NOVA

1|2 B

MAX

HAVO|VWO TTO

Physics & Chemistry

NAME AND CLASS:

MALMBERG

NOVA

1|2 HAVO|VWO TTO Part B

Physics and chemistry

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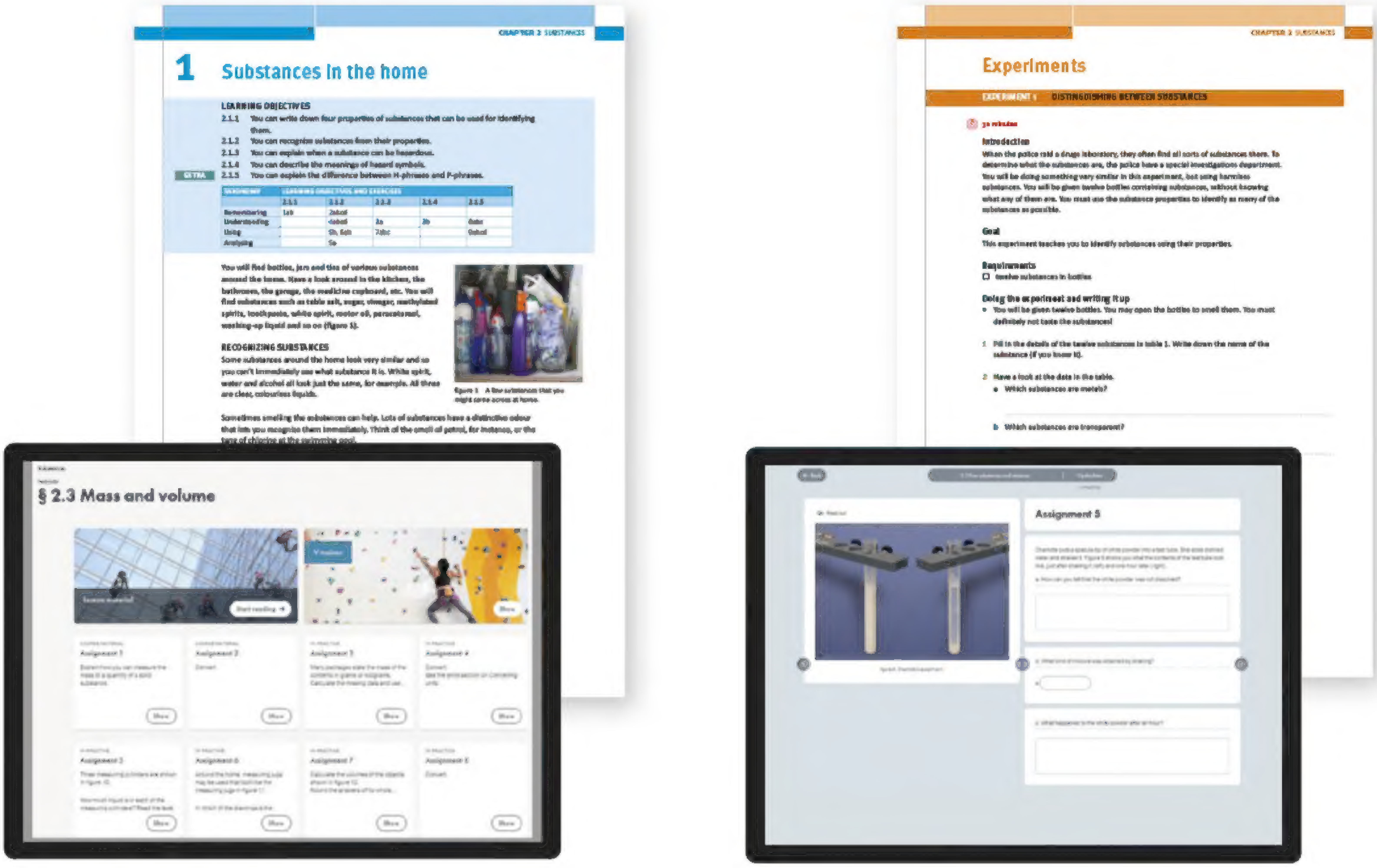


Work in your book *and* work online!

There are two books for each school year plus an online learning environment. Your teacher will decide what you do online (with a laptop, tablet or mobile) and what you do in your book. Each chapter is split up into theoretical sections, experiments, an article about the subject in practice and an overview of the course material. Each section begins by stating the learning objectives that tell you what you will be learning about. You can find additional material at the end of each section. In the *Experiments* section, you will do practical assignments and learn how to study and investigate. At the end of each chapter, there is an *Everyday science* section, an article in which part of the course material is discussed in practice in a situation from daily life or from a scientific context. The closing part contains the *Remember* and *Concepts* sections.

The advantages of working online

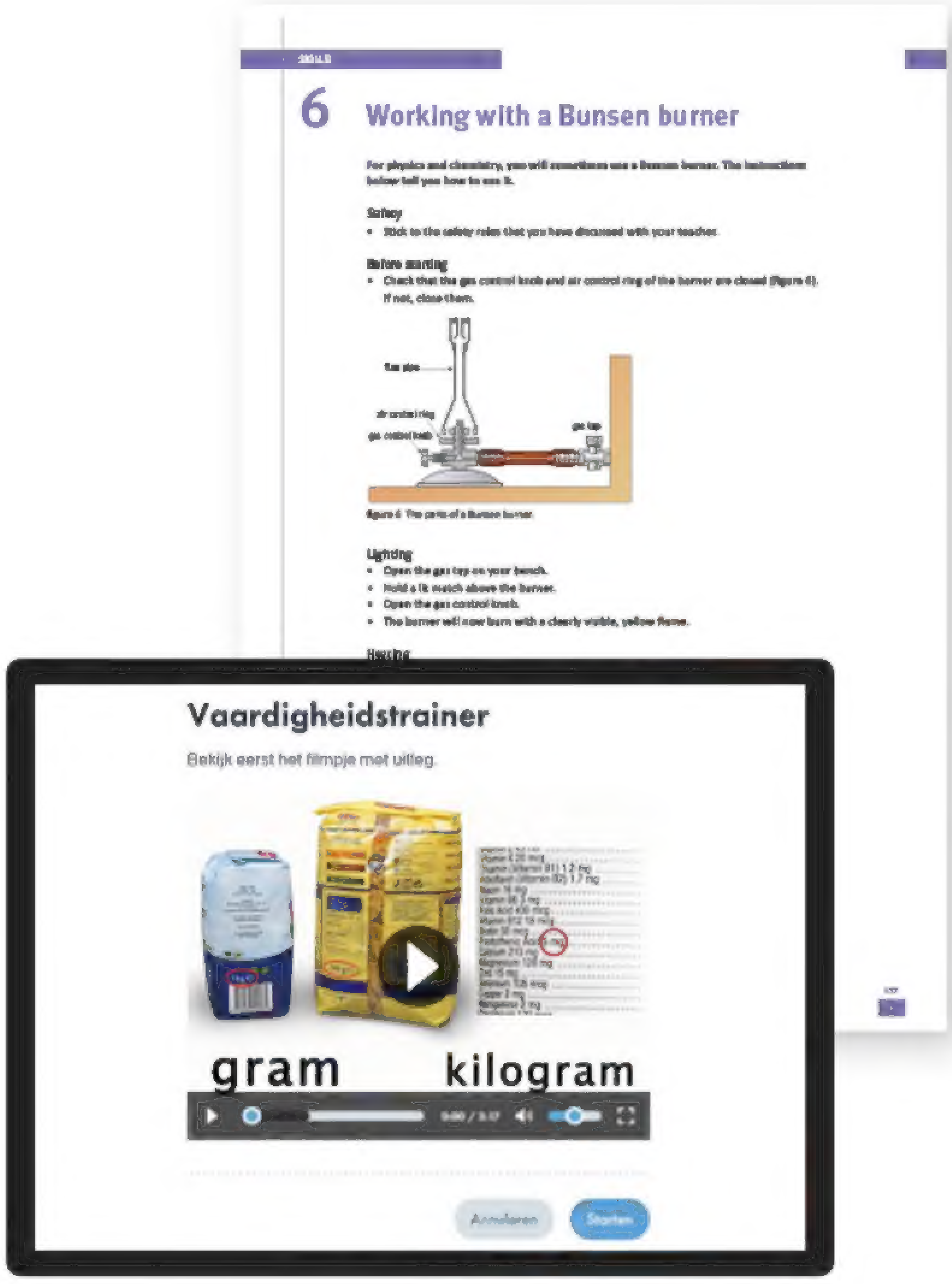
- You will see quickly what you are doing correctly and what you are doing wrong.
- You get feedback on your answers straight away.
- You can watch video clips and animated clips.
- You can practice important skills with the Skills Trainer.
- You learn the concepts using the *Flash cards*.
- You can use the *Test yourself* sections, the *Practice test* and the *Diagnostic test* to measure whether you have understood the material.
- You can work at a higher or lower level or for a different school year.
- Your teacher will monitor how you are progressing.

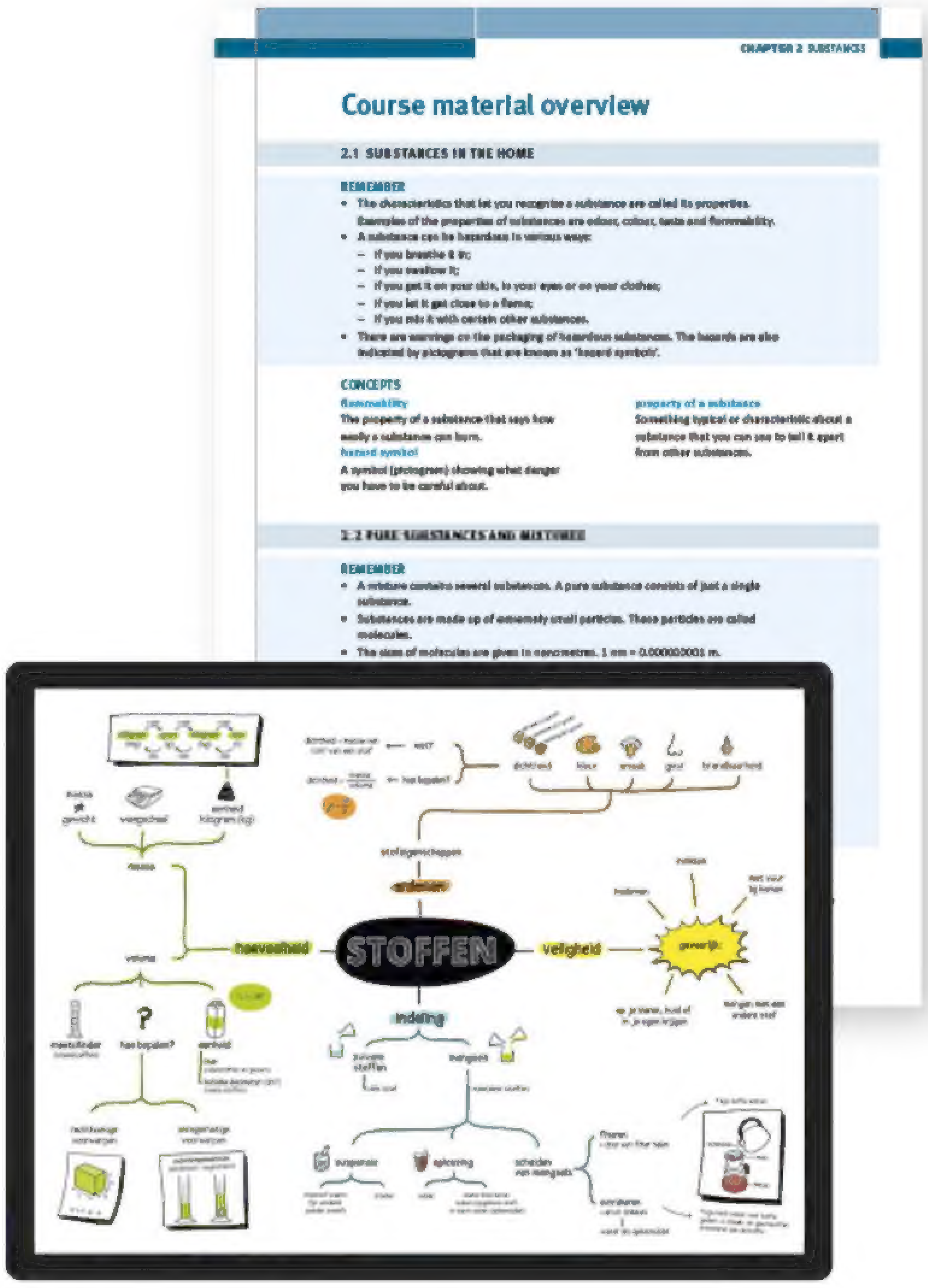
Skills

At the end of each book, you will find a *Skills* section in which the key skills for doing research and investigating are explained. A number of important skills can also be practised online with the Skills Trainer.

Good preparation for the test!

The *Remember* and *Concepts* sections at the end of each chapter in the book will help you prepare for the test. Each chapter ends with an online *Completion* section that contains a *Summary assignment*. This is also where you can find the *Flash cards* for learning all the concepts. There is also a *Diagnostic test*. If you are not sure that you understand the material well enough, you can do the *Test yourself* section or the *Practice test*.





The advantages of the book

- You get a quick overview of what you will be learning.
- You can read the longer texts on paper.
- You can annotate the text and add remarks.
- You will be making drawings and adding colour yourself, which helps you remember the course material better.

Meaning of the symbols

	go to the online learning environment for some useful extras
EXP. 1	there is an experiment for this classroom materia
	use the skills for this assignment
	this is how long this experiment will take you
	this assignment is extra challenging

Contents Part A

Contents Part B

5 Movement

SPORT AND TRAFFIC

Movement is crucial in sports and in traffic. That is why all kinds of techniques have been developed for recording, analysing and describing motion. The results are used to make traffic safer and to improve sporting performance.

1 Recording movements

LEARNING OBJECTIVES

5.1.1 You can explain the two ways of recording a movement.
5.1.2 You can state the two variables that you have to know in order to get the data for a distance-time diagram from a video recording or a stroboscopic photograph.
5.1.3 You can complete a distance-time table.
5.1.4 You can determine the distance associated with a given time on a distance-time diagram or (x,t) diagram and vice versa.
5.1.5 You can explain what the distance covered means.
EXTRA 5.1.6 You can explain how you make a finishing photo.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	5.1.1	5.1.2	5.1.3	5.1.4	5.1.5	5.1.6
Remembering	1abc			1d		9abcd, 10a
Understanding	3, 4ab, 5a	2		8b		10bef
Using		5b, 6abc	7a	8a	7bc	10c
Analysing				8c		10dg

Many movements are so quick that you cannot follow them properly with the naked eye. People do still sometimes want to know how that movement proceeds, though. High-jumpers and gymnasts can for example use that information to improve their performance. That is why various methods have been developed for recording and analysing motion.

FILMING MOTION

You can record a motion by filming a moving object with a video camera or a smartphone. The device then stores a **video recording**: a series of images that are made at short intervals (figure 1). Many video cameras make recordings at thirty frames (pictures) per second or 30 fps. The time between two successive images is then 1/30 s (= 0.033 s).

figure 1 A series of frames from a video recording.

There are computer programs that you can use to analyse a video recording one frame at a time. The program then collects data about the location and speed of the object and presents it in a table or graph.

Not all video recordings can be analysed that way. To get good results, you need a recording in which the object is moving past a stationary camera. The recording also has to show a ruler or other object with known dimensions that allows the **scale** of the image to be determined. Finally, you have to know how many frames per second the recording was made at.

TAKING STROBOSCOPIC PHOTOS

You can also record a motion by taking a stroboscopic photo. This type of photograph is taken in a darkened room, using a stroboscope as the only light source. This is a light that gives very short flashes of light at regular intervals. There is a knob on the stroboscope that lets you adjust the time between two successive flashes.

The camera shutter remains open throughout the movement. Every time that the light flashes, the progress of the movement at that moment is recorded. All the individually recorded images appear together on a single photograph. Figure 2 shows you an example of a ball rolling down a sloping plane. You can easily see exactly where the ball was at each moment.

figure 2 A stroboscopic photograph of a rolling ball.

A video recording of a movement consists of a whole series of images. You can use a computer program to process those images into a single combined picture. That gives you something very similar to a stroboscopic photo. Figure 3 is an example of this.

figure 3 A 'stroboscopic photo' generated from a video recording.

COMPLETING A DISTANCE-TIME TABLE

To analyse the linear motion of the rolling ball in figure 2, you can make a **distance-time table**. The data for this kind of table can be obtained from a video recording or a stroboscopic photograph. You do then need to know:

- the time intervals between the individual frames;
- the actual distances represented in the images.

In the motion of the rolling ball, the interval between successive flashes of light is 0.5 s. The position of the ball can be read off the ruler. Always look at the same point on the ball when you do that (its right-hand edge, for example).

Once you know all this, you can fill in the distance-time table.

- The motion starts at A. The right-hand side of the ball is exactly aligned with the zero on the ruler. So you enter the following into table 1 for point A: time = 0 s and distance = 0 cm.
- You then read off where the ball is for B: 3 cm. You write down the following in the table for point B: time = 0.5 s and distance = 3 cm.
- After that, you read off where the ball is for C: 10 cm. So the entry for point C says: time = 1.0 s and distance = 10 cm.

Work out for yourself how the rest of table 1 should be filled in.

table 1 A distance-time table.

	time (s)	distance (cm)
A	0	0
B	0.5	3
C	1.0	10
D	1.5	
E		
F		

DRAWING A DISTANCE-TIME DIAGRAM

You can use the data from a distance-time table to draw a graph of the movement. This kind of graph is called a **distance-time diagram** or **(*x*,*t*) diagram**. The letter *x* represents the distance and the *t* stands for time. The (*x*,*t*) diagram for the motion shown in figure 2 has been drawn in figure 4. You can use an (*x*,*t*) diagram to read off the corresponding position for any moment in time, and vice versa.

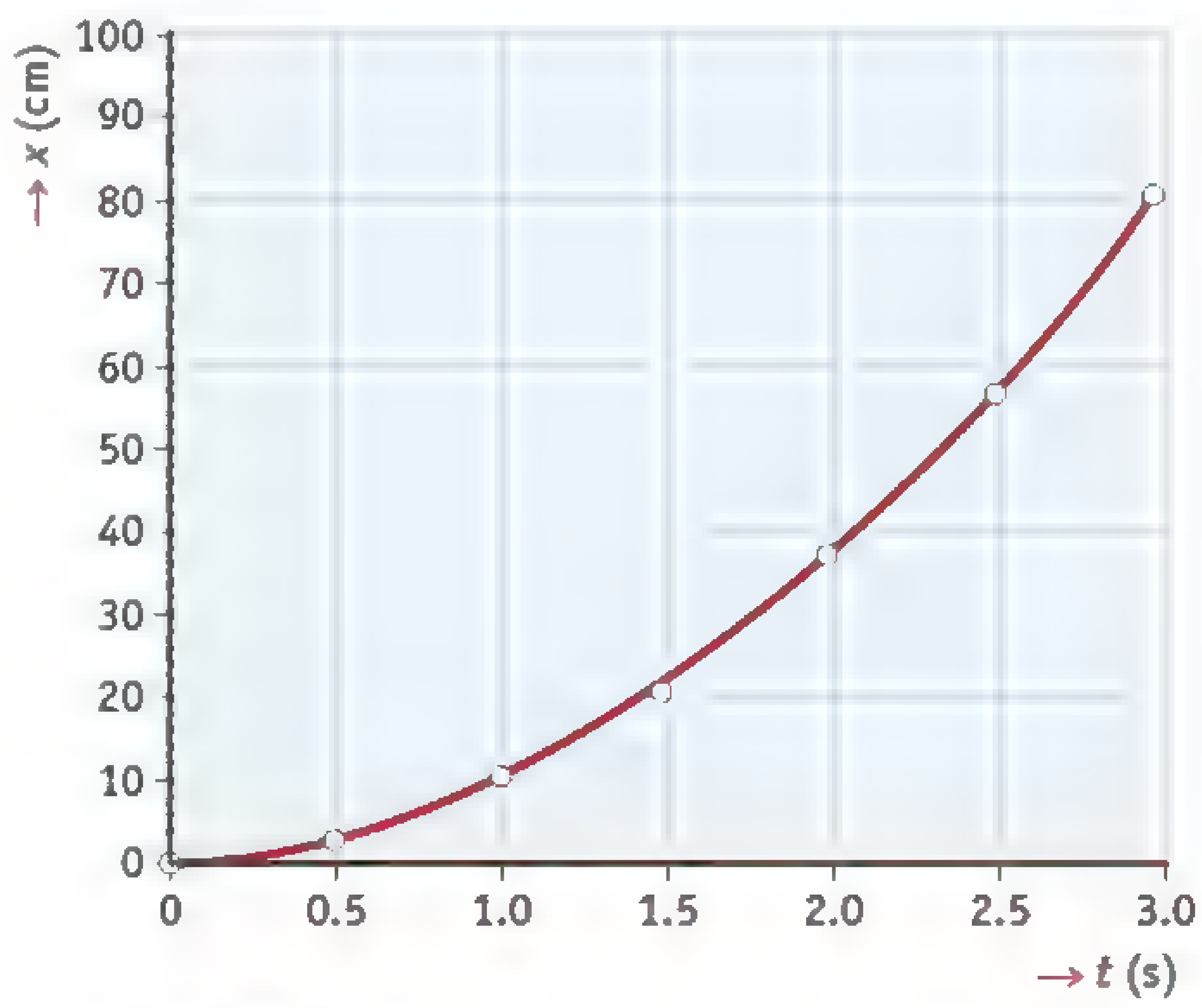


figure 4 The (*x*,*t*) diagram of the rolling ball.

DISTANCE TRAVELLED

On a distance-time diagram or (x,t) diagram, you can read off the distance covered s. In the (x,t) diagram of the rolling ball in figure 4, you can read off that the difference in position between time $t = 0$ s and time $t = 2.0$ s is 37 cm ($s = 37$ cm – 0 cm = 37 cm). Between time $t = 0.5$ s and $t = 1.0$ s, the ball travelled a distance of 10 cm – 3 cm = 7 cm. So you write down $s = 7$ cm. The distance travelled is therefore always the difference between two measured values.

Practice the concepts using the *Flash cards*.

EXTRA FINISHING PHOTOS

In the 100 metres, the sprinters often cross the finishing line at almost the same time. Sometimes the jury needs a photograph of the finish to determine who won the race. The photo shows clearly what order the athletes crossed the finishing line in.

A finishing photograph is made using a special camera. A screen with a vertical slit is placed in front of the camera lens through which a narrow strip of the track can be seen at the finishing line. If you take a single photo with the camera, you get a narrow image showing only the finishing line (figure 5).

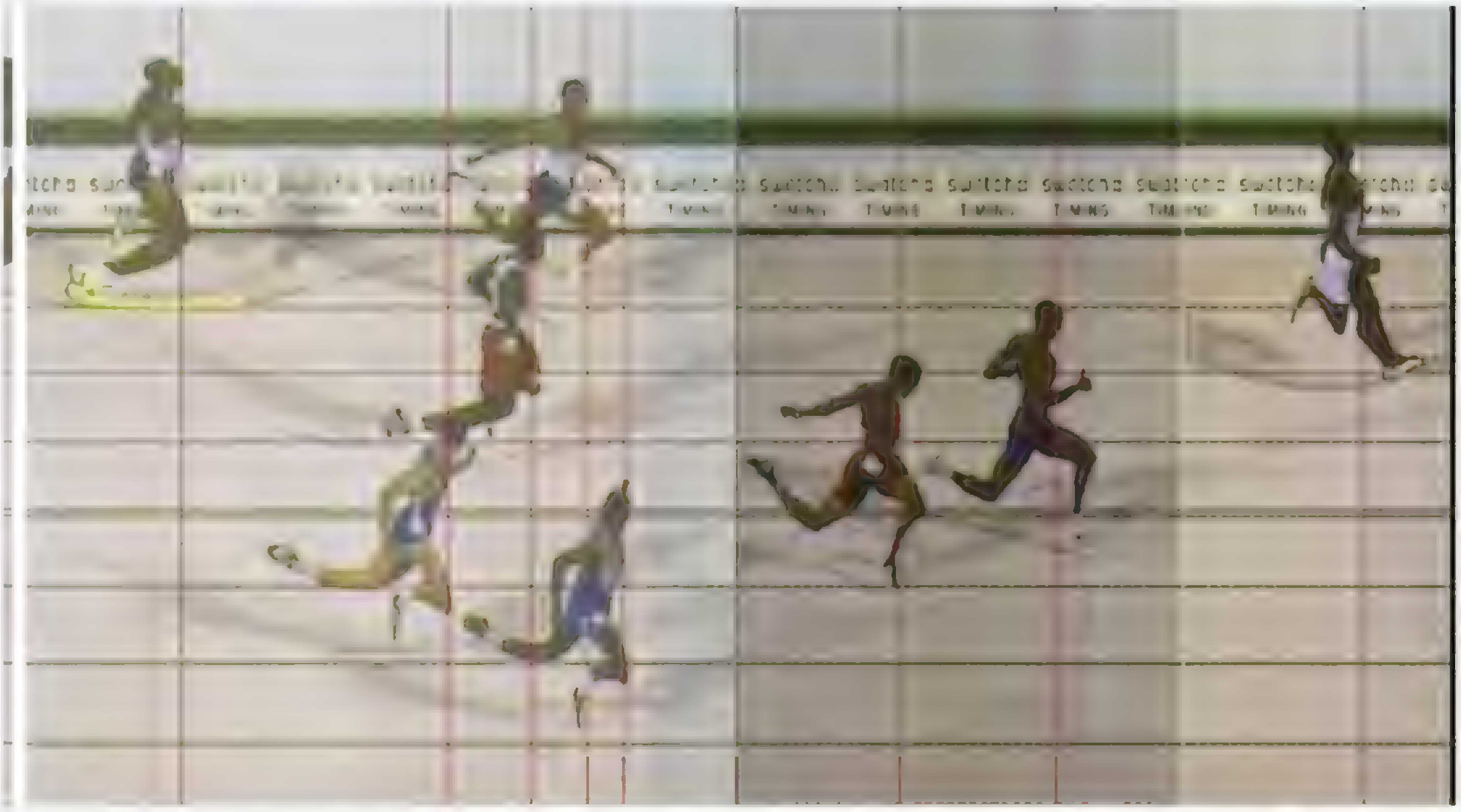


figure 5 A photo finish consists of a series of images placed next to one another. The narrow strip on the left is a single camera photo; the whole finishing photo can be seen on the right.

A modern photo-finish camera can take thousands of photographs every second. Each image is just a single pixel wide. The finishing photograph consists of a whole series of these photographs next to one another. Together, these images make up the photo finish. The athlete who crossed the finishing line first is on the right and the last athlete is on the left.

COURSE MATERIAL

1 Answer the following questions.

a How can you record a rapid motion? Write down two methods.
b What is the name for a device that gives flashes of light at regular intervals?
c What is the name for a photograph taken using this kind of light?
d What do we mean by the '(x,t) diagram' of a motion?

2 Redwan has made a video recording of a falling basketball. Now he would like to make a distance-time table for that movement.
Which two things must he first find out before he can fill in the table?

IN PRACTICE

3 Peter is working with a program for analysing video images. He wants to get the program to draw an (x,t) diagram for an accelerating car. His teacher warns him that you cannot just use any old video recording to do that: "The camera has to be stationary while the recording is being made."
What will go wrong if the camera pans to follow the car?

4 Figure 6 shows two photographs. The camera shutter remained open the whole time while the photo was being taken.

a In which photo is the table-tennis player lit by a normal light? How can you tell?
b In which photo is the table-tennis player illuminated by a stroboscope? How can you tell?

figure 6 Normal light or stroboscope?

5

The photo in figure 7 was taken using a stroboscope.

a How many times did the light flash during the jump?

b The time interval between two flashes of light is 0.15 s.
How long did the entire motion take (from the first recorded moment to the last)?

figure 7 The motion of a high-jumper.

6

Figure 8 shows you a stroboscopic photo of a bouncing ball.

a When is the ball moving fastest? How can you tell?

b When is the ball's motion slowest? How can you tell?

c The ball hits the ground at A and B. The time between two successive light flashes is 0.05 s.
How much time is there between points A and B?

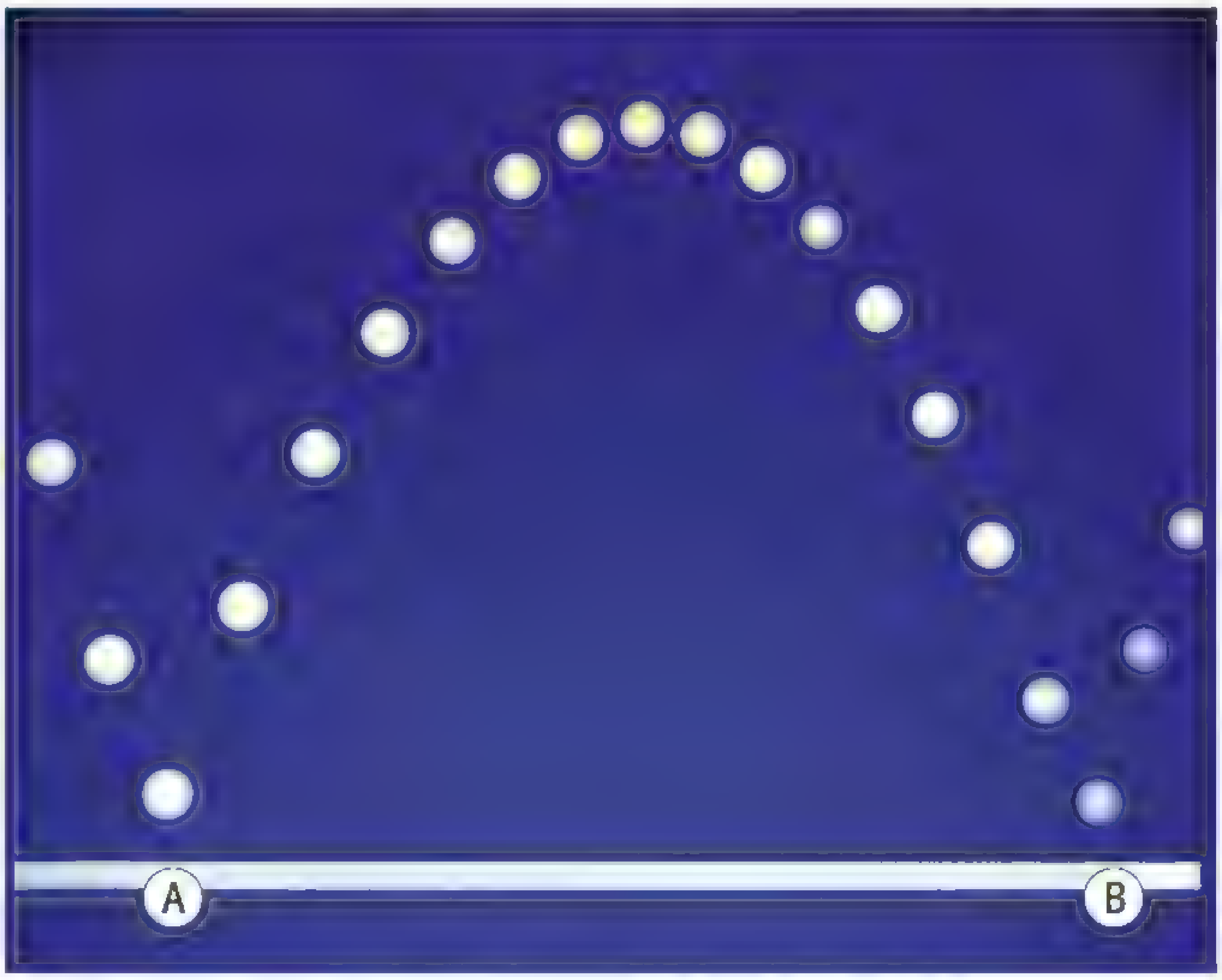


figure 8 A bouncing ball.

7

Figure 9 shows you a stroboscopic photo of the motion of a toy car. The time between two successive images is 0.2 s.

a Fill in the distance-time table (table 2) completely.

table 2 A distance-time table.

time (s)	distance (cm)
0	0
0.2	....
....	....
....	....
....	....
....	....
....	....

b What distance did the car travel between times t = 0.2 s and t = 1.0 s?

c What distance did the car travel between times t = 0.8 s and t = 1.2 s?

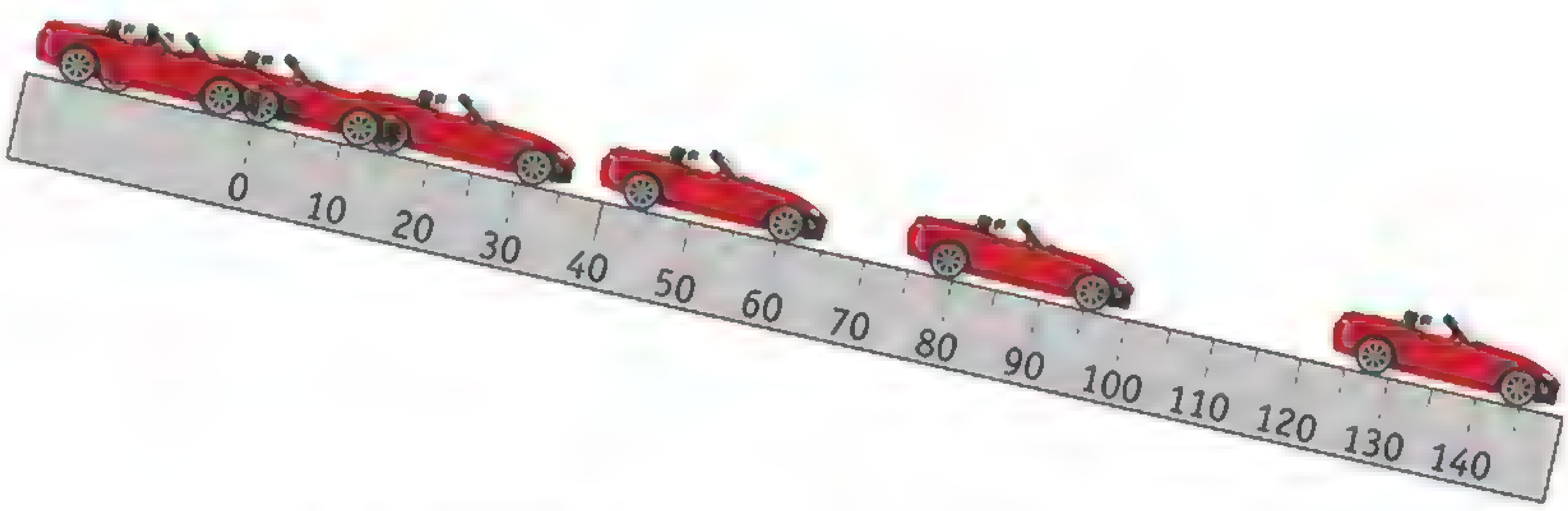


figure 9 A stroboscopic photograph of a toy car.

★ 8

Figure 10 shows you a video recording of a gymnast jumping on a trampoline. The diagram plots the height against the time.

a Complete the following:

.... complete jumps were measured in this example.

b Complete the following:

At the top of the jump at time t = ... s, the height you write down is

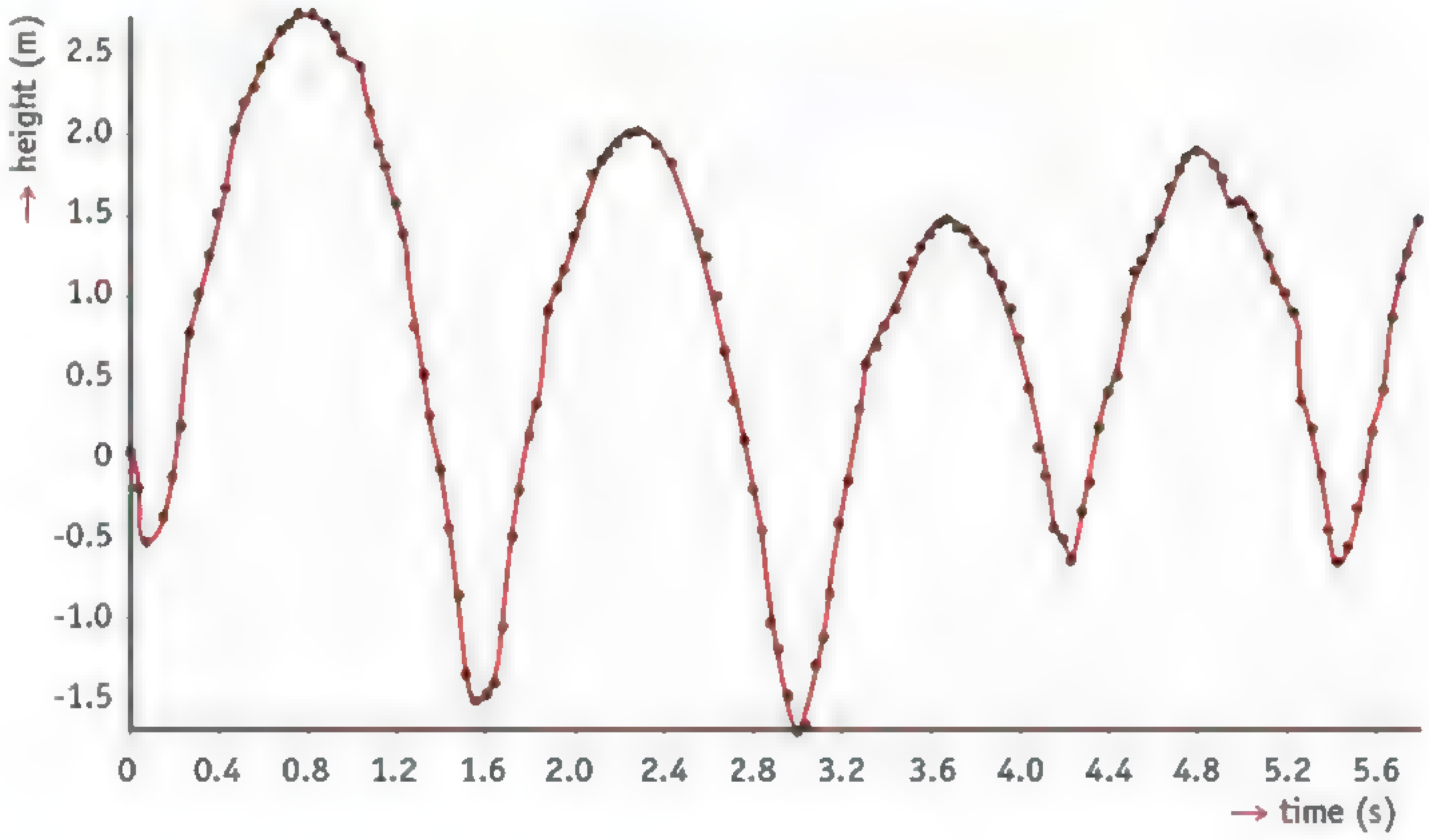
h = ... m.

At the bottom of the jump at time t = ... s, the height you write down is

h = ... m.

c At what moments was the trampolinist moving most slowly?

figure 10 A video measurement of a series of jumps on a trampoline.



Test what you know with *Test yourself*.

EXTRA FINISHING PHOTOS

9 A finishing photograph is made using a special camera.
Complete.

a A screen with a .... slit has been placed in front of this camera's lens.

b Through this slit, a narrow strip of the .... can be seen at the ....

c If you take a single photo, you get a narrow image showing only the ....

d A photo finish consists of a series of .... next to one another, all .... in width.

★ 10

Figure 11 shows you the photo finish for the men's 100 metres. The times for the athletes are given at the bottom.

a Where in the photo are the runners with the fastest times? *left / right*

b What is the winner's time?

c What part of the body counts for determining the finishing time (and therefore also for deciding the winner)?

d The picture of the foot of the runner in lane 2 seems to be stretched out peculiarly. Explain why.

e How much time is there between the winner and the sprinter finishing last?

f How much distance is there in the photo (in centimetres) between the winner and the sprinter finishing last?

g Calculate the time difference represented by a one-centimetre difference on the finishing photo.

IAAF World Championships London 2017 - 100 Metres Men (8-9-6)

Place	Id	Lane	Last Name	Affil	Time	ReacTime
1	1075	7	Bolt	JAM	10.07	0.166
2	953	4	Dasaolu	GBR	10.13	0.122
3	943	3	Vicaut	FRA	10.15	0.154
4	1120	6	Tada	JPN	10.19	0.175
5	1052	9	Taftian	IRI	10.34	0.177
6	762	2	Rodney	CAN	10.36	0.166
7	665	8	Fraser	BAH	10.42	0.166
8	797	5	Palomeque	COL	10.51	0.149

figure 11 The finishing photo for the final of the 100-metre sprint (2017 World Championships).

2 Average speed

LEARNING OBJECTIVES

5.2.1 You can do calculations using the formula for the average speed.
5.2.2 You can calculate the average speed using a given distance-time diagram or (x,t) diagram.
5.2.3 You can convert a speed in m/s to km/h and vice versa.
5.2.4 You can read off a speed-time diagram or (v,t) diagram.
5.2.5 You can calculate the average speed if the speed is increasing steadily.
EXTRA 5.2.6 You can explain how a step counter works.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	5.2.1	5.2.2	5.2.3	5.2.4	5.2.5	5.2.6
Remembering	1ab, 3		2ab			
Understanding	4			10a		12a, 13ab
Using	5a, 7ab, 8a, 9, 10c				10b	12bc, 13cde
Analysing	5b, 6b, 8b	11b	6a	11a		12d

A cyclist who covers a stage of 184 kilometres in 4 hours has been going at an average speed of 46 kilometres per hour (km/h). This does not mean that his speed was exactly 46 km/h the whole time, of course. But if he had gone at a constant 46 km/h, he would have covered the same distance (184 km) in the same time (4 hours).

CALCULATING THE AVERAGE SPEED

The average speed often gives you a good impression of how quickly something or someone is moving. You can calculate the average speed by dividing the distance covered by the time taken:

$$\text{average speed} = \frac{\text{distance travelled}}{\text{time}}$$

Or in symbols:

$$v_{avg} = \frac{s}{t}$$

where:
- v_{avg} is the average speed in metres per second (m/s);
- s is the distance travelled in metres (m);
- t is the time in seconds (s).

If you use a distance covered in kilometres and a time in hours, you get the average speed in kilometres per hour (km/h).

EXAMPLE EXERCISE 1

In the women's event, a sprinter runs the hundred metres in 10.8 s (figure 1).
Calculate her average speed.

given $s = 100$ m
$t = 10.8$ s

required $v_{avg} = ?$

working $v_{avg} = \frac{s}{t} = \frac{100}{10.8} = 9.3$ m/s

figure 1 Athletes at full speed in the 100 metres sprint.

EXAMPLE EXERCISE 2

Ben cycles to school every day. Figure 2 shows you the distance-time diagram for one of his cycle rides. At point A in the graph, Ben realized that he was a bit late and started cycling faster.
Calculate Ben's average speed from point A until he got to school.

given $s = 4.0 - 1.6 = 2.4$ km $= 2400$ m
$t = 14 - 7.5 = 6.5$ min $= 390$ s

required $v_{avg} = ?$

working $v_{avg} = \frac{s}{t} = \frac{2400}{390} = 6.15$ m/s

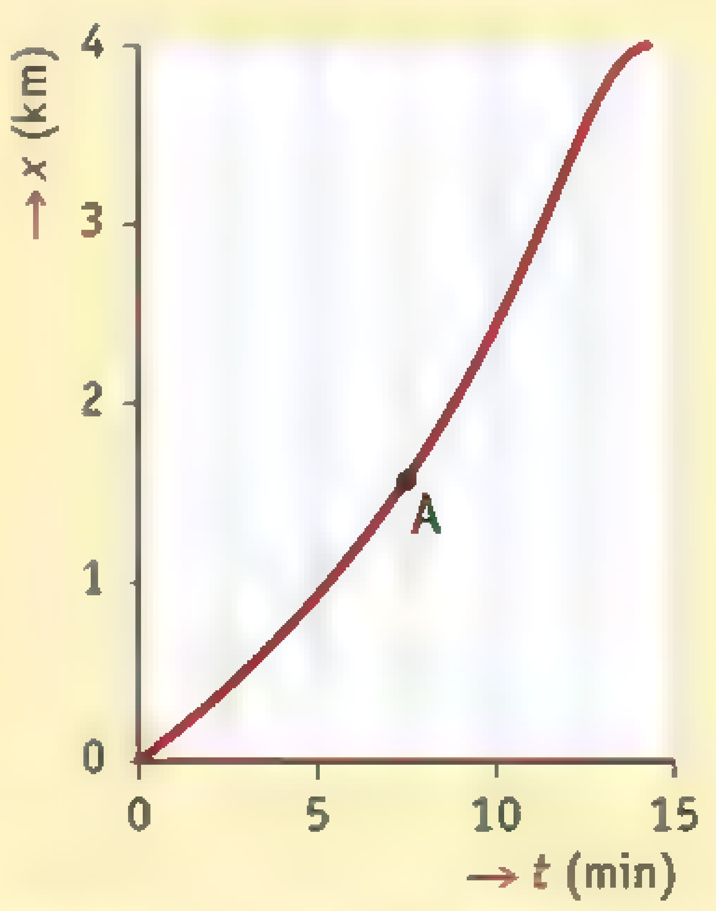


figure 2 The (x,t) diagram of a cycle ride from home to school.

CONVERTING SPEEDS

It is often useful to be able to convert speeds from metres per second (m/s) to kilometres per hour (km/h) and vice versa. If you convert 6.15 m/s, you get a speed (rounded off) of 22.1 km/h. That probably means more to you than 6.15 m/s, because you are used to expressing speeds in km/h.

To be able to convert the speeds, you need to know that:
1 km = 1000 m
1 h = 3600 s

For a speed of 10 m/s, the logic is as follows: if you cover 10 metres in 1 second, then (at the same speed) you would cover 3600 x 10 metres in 1 hour. So you can write:

$$10 \text{ m/s} = \frac{3600 \times 10 \text{ m}}{3600 \times 1 \text{ s}} = \frac{36{,}000 \text{ m}}{3600 \text{ s}} = \frac{36 \text{ km}}{1 \text{ h}} = 36 \text{ km/h}$$

Check that multiplying by 3.6 gives the same result (figure 3).

Converting from km/h to m/s goes like this:

$$90 \text{ km/h} = \frac{90 \text{ km}}{1 \text{ h}} = \frac{90{,}000 \text{ m}}{3600 \text{ s}} = 25 \text{ m/s}$$

Check that this is the same as dividing by 3.6.

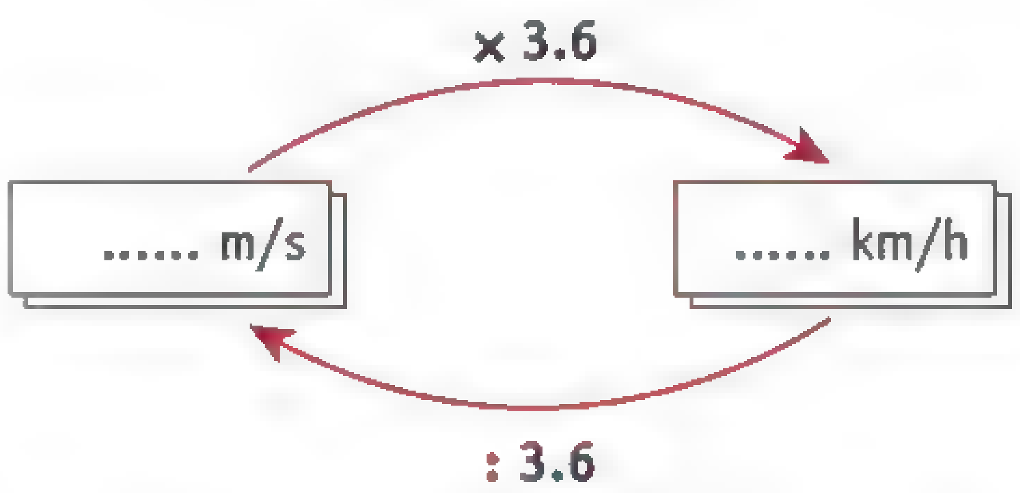


figure 3 A flow diagram for converting m/s to km/h and vice versa.

CALCULATING TIME AND DISTANCE

You can use the formula:

$$v_{avg} = \frac{s}{t}$$

to work out the distance or the time as well. It is then useful to write down the formula in a different way, with the variable you want on the left.

If you know the average speed and the time, you can work out the distance travelled. You can then rewrite the formula as:

$$s = v_{avg} \cdot t$$

If the average speed and the distance covered are known, you can calculate the time needed for the movement. In that case, you can rewrite the formula as:

$$t = \frac{s}{v_{avg}}$$

EXAMPLE EXERCISE 3

A motorist knows that he can easily manage an average speed of 90 km/h for a particular route. The whole route takes him about 6 hours.
What approximate distance is he travelling?

given $v_{avg} = 90$ km/h
$t = 6$ h

required $s = ?$

working $s = v_{avg} \cdot t = 90 \times 6 = 540$ km

EXAMPLE EXERCISE 4

When Annette goes on a long hike of 50 km, her average speed (including rest stops) is 4 km/h (figure 4).
Calculate how long the trip takes her.

given $s = 50$ km
$v_{avg} = 4$ km/h

required $t = ?$

working $t = \frac{s}{v_{avg}} = \frac{50}{4} = 12.5$ hours

figure 4 Annette has nearly completed the 50 km.

SPEED-TIME DIAGRAMS

You can record a motion as a distance-time diagram or as a **speed-time diagram**, which is also known as a **(v,t) diagram**. Figure 5 shows you the (v,t) diagram for a car that is moving faster and faster.
You can see that the speed increases very regularly from 0 m/s at $t = 0$ s to 20 m/s at $t = 8$ s. It is easy to use the graph to find the average speed: it is the speed that is exactly in the middle, in this case 10 m/s.

If the speed increases regularly, the 'curve' in the (v,t) diagram is a straight line (figure 5). You can calculate the average speed using the following formula:

$$v_{avg} = \frac{v_{init} + v_{final}}{2}$$

where:
- v_{avg} is the average speed in metres per second (m/s);
- v_{init} is the speed at the start of the motion in metres per second (m/s);
- v_{final} is the speed at the end of the motion in metres per second (m/s).

In the example, that gives $v_{avg} = \frac{0 + 20}{2} = 10$ m/s

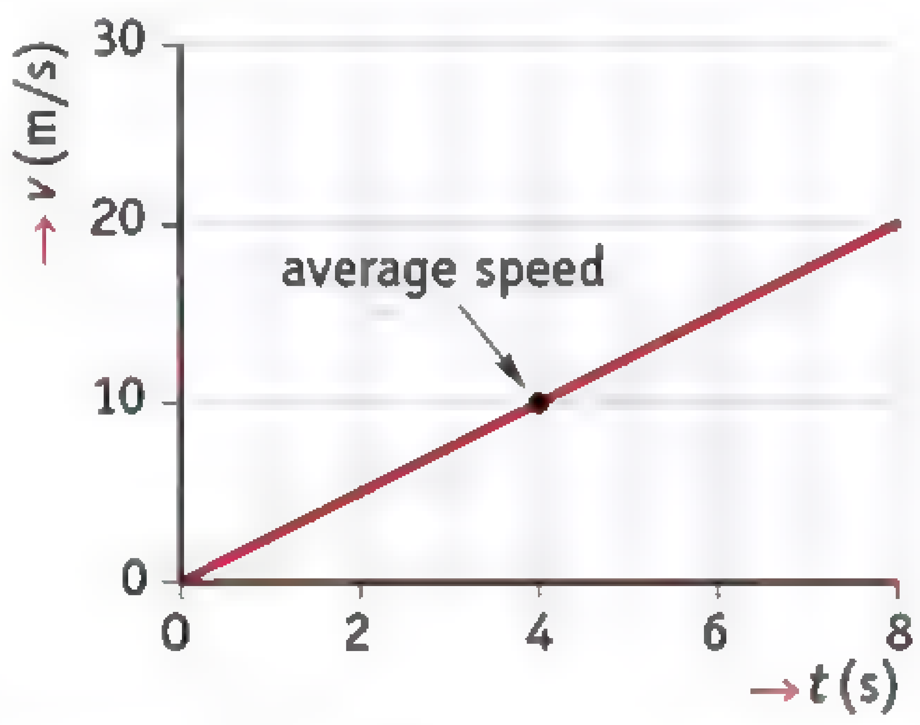


figure 5 The (v,t) diagram for a car.

EXAMPLE EXERCISE 5

Robin's father is braking for the traffic jam he can see up ahead. In twenty seconds, he brakes from 30 m/s to 5 m/s. Figure 6 shows you the (v,t) diagram.
Use the diagram to determine the distance that Robin's father covered between $t = 0$ s and $t = 20$ s.

given $t = 20$ s
read the initial and final speeds from the graph: $v_{init} = 30$ m/s and $v_{final} = 5$ m/s.

required $s = ?$

working $v_{avg} = \frac{v_{init} + v_{final}}{2} = \frac{30 + 5}{2} = 17.5$ m/s

$s = v_{avg} \cdot t = 17.5 \times 20 = 350$ m

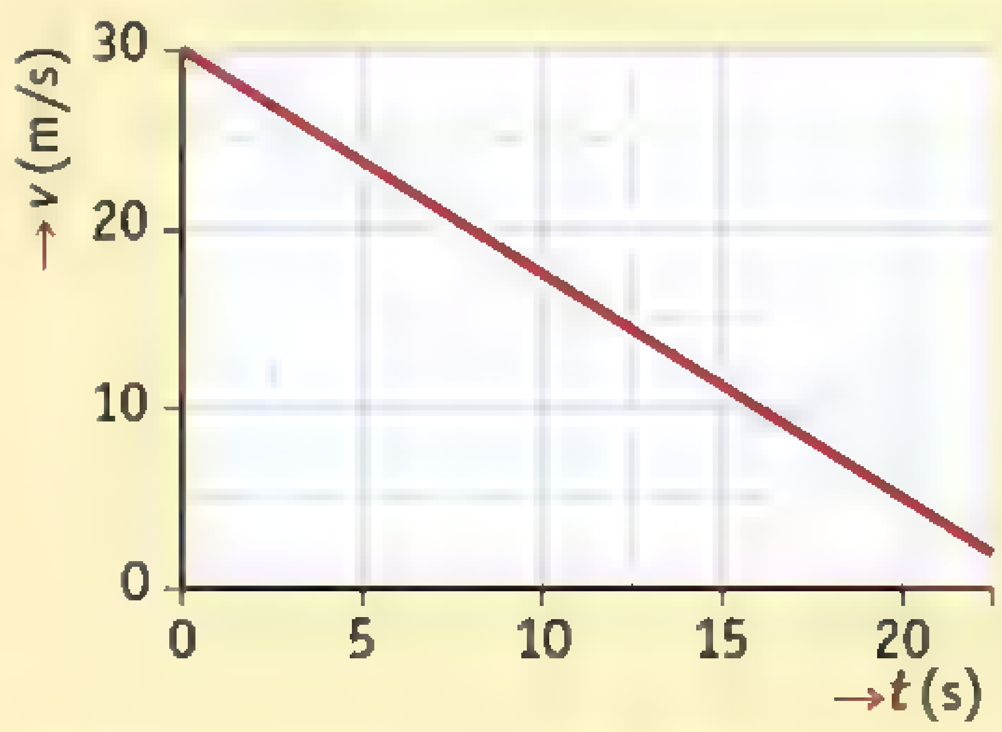


figure 6 Braking for a traffic jam.

Practice the concepts using the *Flash cards*.

EXTRA THE STEP COUNTER

You can find a step counter on many mobile phones and smartwatches (figure 7). As well as the number of steps you have taken, the app also works out the distance you have covered that day. To work out that distance, the app multiplies the number of steps you have taken by the length of a single stride.

Most phones measure the number of steps using acceleration sensors. Those sensors are small electronic chips that can measure whether your speed is increasing or decreasing. When the sensor detects that your speed has increased and then decreased again once, the app knows that you have taken a single step. If you want to install an app like that on your smartphone, you will often find that it is called a 'calorie counter'.

figure 7 A step counter on a smartwatch.

COURSE MATERIAL

1 In road cycling competitions, average speeds are often calculated for the winner and for the main pack (also known as the 'peloton').

a What data do you need in order to be able to calculate the average speed?
b What formula (in symbols) can you then use to work out the average speed?

2 You can give the average speed in m/s or in km/h.

a How can you convert a speed in m/s quickly to km/h?
b How can you convert a speed in km/h quickly to m/s?

3 If you know the average speed and the time, you can work out the distance travelled. What formula do you use for that?

IN PRACTICE

4 Table 1 shows the data for five movements.
Complete the missing data in the table.

table 1 Distance, time and average speed.

distance	time	average speed
45 km	45 min	.... km/h
4.5 km	80 min	.... m/s
200 m	.... s	9.0 m/s
.... km	2 h	85 km/h
20 km	.... min	90 km/h

5 The Richards family are going on holiday by car. The distance from their home in Drachten (in the Netherlands) to their holiday address in Confolens (in central France) is 1100 km. They leave at 04:00 in the morning and arrive at 17:00 that same afternoon.

- **a** Calculate the average speed in km/h.
- **b** The car is going at more than 120 km/h for most of the journey. Even so, the average speed was a lot lower.
  What might be the reason?

6 At the athletics World Junior Championships in 2018, the American Eric Harrison ran the 100 metres in 10.39 s and the 200 metres in 20.73 s.

- **a** Calculate the average speeds for both distances in m/s and km/h.
  Show all your calculation steps.
- **b** His average speed for the 200 metres was faster than for the 100 metres.
  Give an explanation for this.

7 Luke is going on a cycling trip. Because he has a cycling computer, he knows that his average speed on a trip like this is 18 km/h.

- **a** Luke has planned a route through the countryside from Arnhem to Harderwijk. The route is 63 km long.
  Calculate how long it will take him to cover the distance.
- **b** One day later, Luke wants to go on another trip. He does not want it to take more than 6 hours.
  Work out the maximum distance Luke will be able to cover in those 6 hours if his average speed is 18 km/h.

8 A triathlon competitor does the 3.8-kilometre swim in 2 hours, the 180-kilometre bike ride in 5 hours and the 42.2-kilometre marathon in 3 hours.

- **a** Calculate the average speeds (in km/h) for each of the three disciplines individually.
- **b** Calculate the average speed for the whole triathlon.

9 Bilal is driving towards a traffic light in a built-up area at a speed of 50 km/h. When he is 300 m away from the traffic light, he sees it turn green. He knows that the traffic light will stay green for 20 s.
Work out whether he can get through the green light without breaking the speed limit of 50 km/h.

10

Figure 8 shows you the (v,t) diagram of a car.

a How can you read the average speed of the car from this kind of diagram?

b Calculate the average speed using a formula.

c Calculate how many metres the car covered between 0 and 8 s.

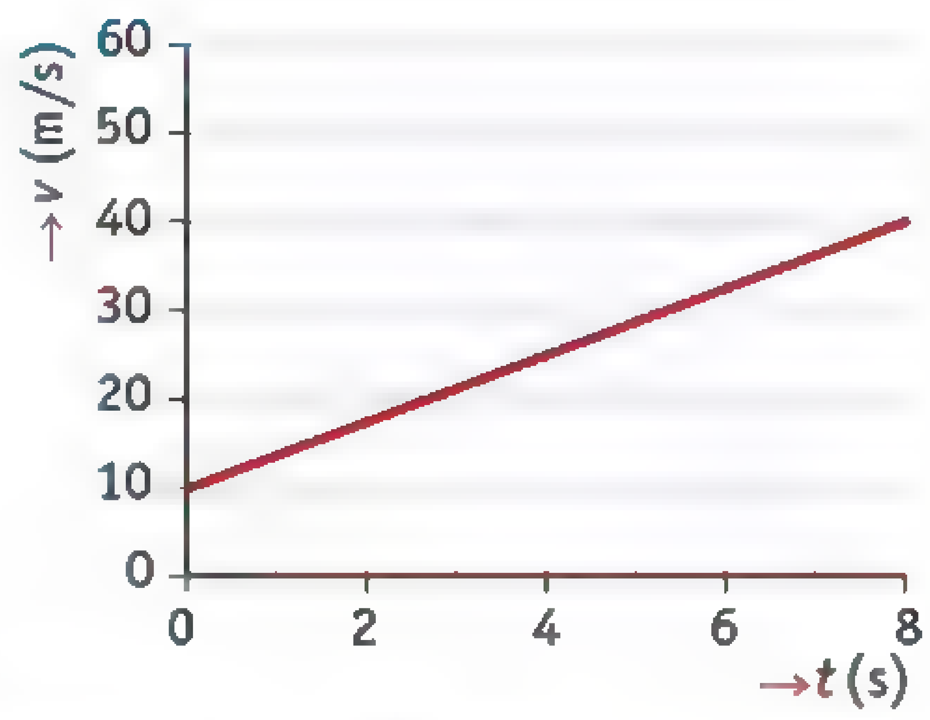


figure 8 The (v,t) diagram for a car.

★ 11

Figure 9 shows the (x,t) diagram for a sprinter in the hundred metres.

a Calculate the sprinter's average speed over the entire race in km/h.

b The athlete's speed was constant for much of the time.
Calculate that speed in km/h.

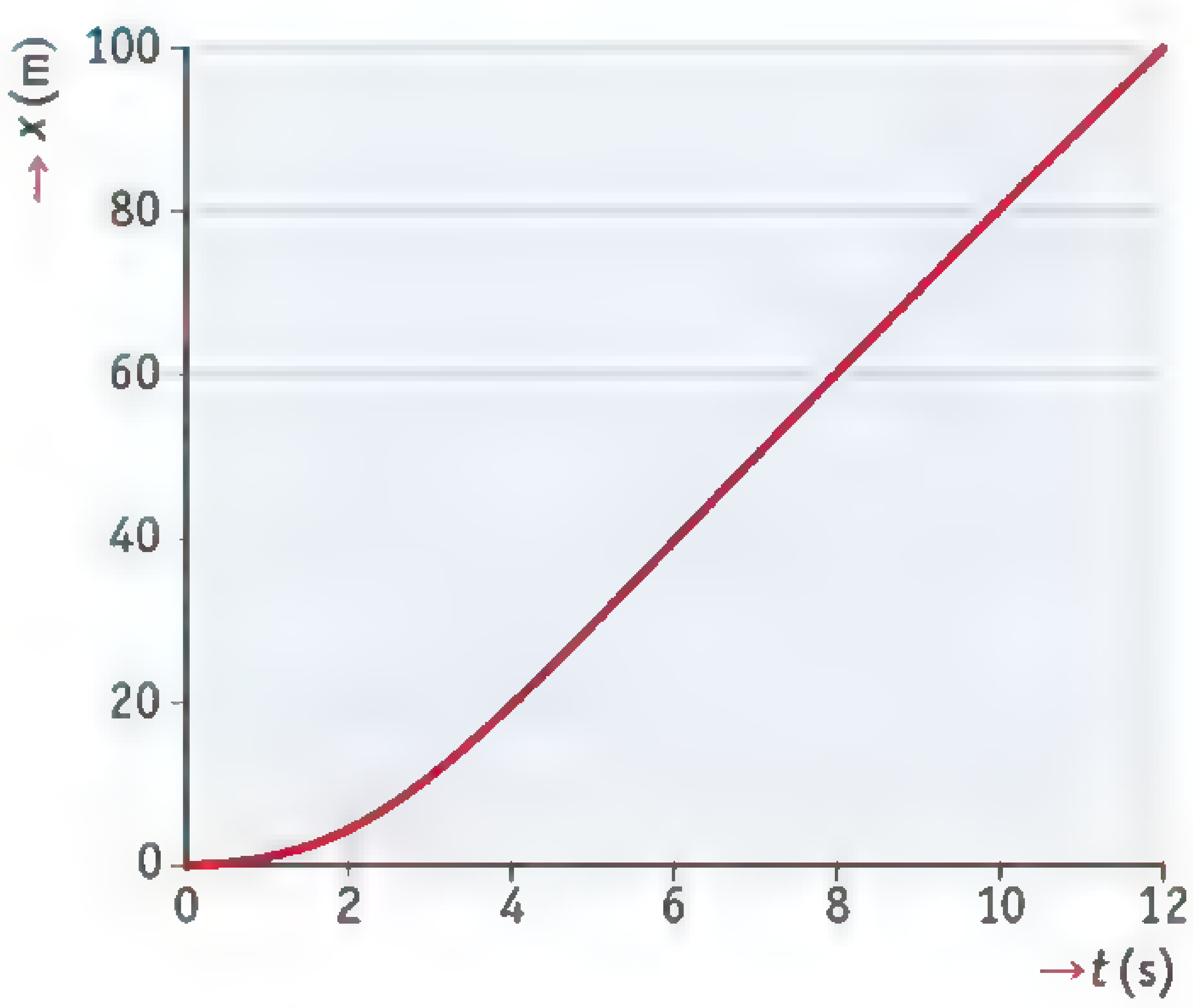


figure 9 The (x,t) diagram for a sprinter.

Test what you know with *Test yourself.*

EXTRA THE STEP COUNTER

12 When you install a simple version of the step counter app on your mobile, you have to tell it how tall you are.

a Explain why the program needs that information.

b When setting up the app, you usually also have to enter your mass.
What does the program need that information for?

c Keira has covered a distance of 3.6 km during a hike. Her step counter tells her that she walked 4800 steps.
Calculate the average stride length.

d Each step took 0.5 s (on average).
Calculate her average speed in km/h.

★ 13 There are also step counters that you can attach round your ankle. Emily wants to do an experiment to check whether the step counter shows the distance reliably. Figure 10 shows you the (x,t) diagram of the movement of her foot that she made during the experiment.

a Explain what the speed of the foot is while it is standing on the ground.

b Write down two times between which the foot is on the ground.

c Write down a time where the speed of the foot is greatest.

d Emily's step counter reads a distance covered of 24 m after thirty steps.
Work out whether that distance is the same as the data you can see in figure 10.

e Calculate Emily's average speed during the experiment.

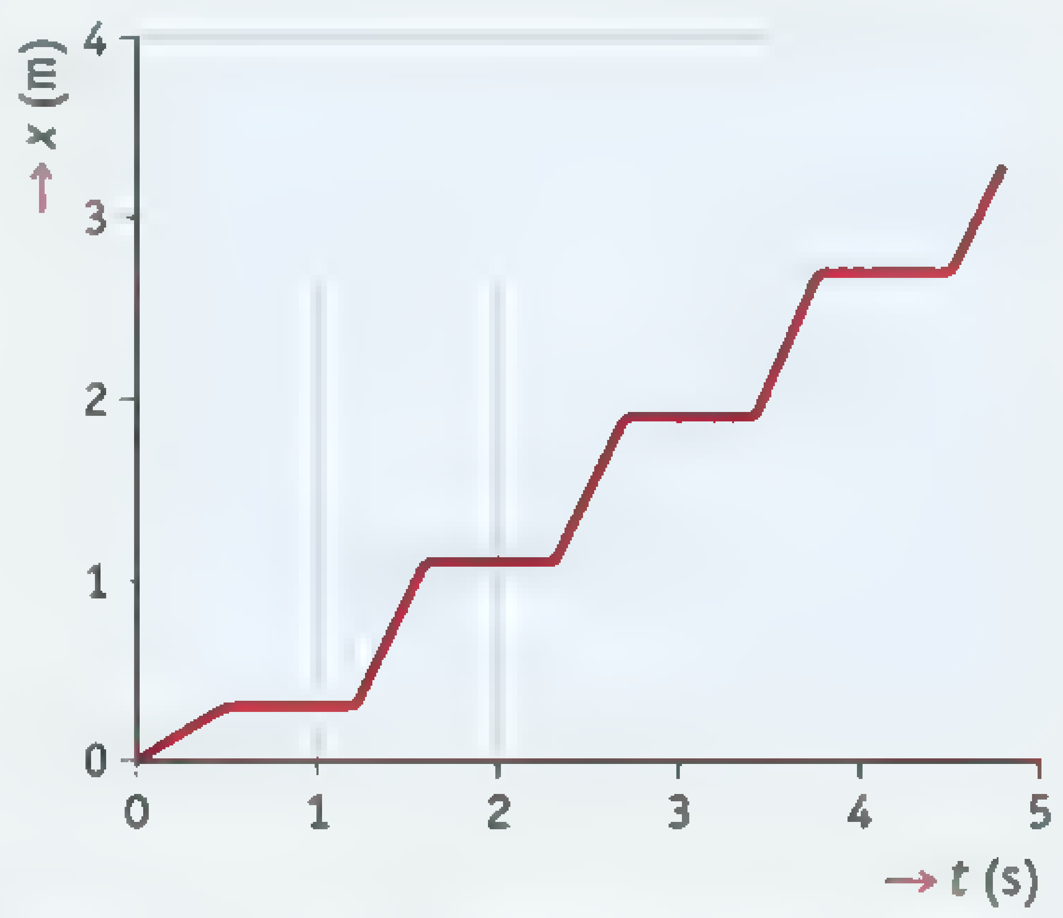


figure 10 The (x,t) diagram for the motion of a foot.

3 Acceleration – uniform motion – deceleration

LEARNING OBJECTIVES

5.3.1 You can explain what happens to the speed in uniform, accelerating and decelerating motions.

5.3.2 You can calculate the speed at any moment of the motion in a uniform motion.

5.3.3 You can recognize the (x,t) and (v,t) diagrams for uniform, accelerating and decelerating motions.

5.3.4 You can read off the (x,t) and (v,t) diagrams for uniform, accelerating and decelerating motions.

5.3.5 You can use an (x,t) diagram to work out when two road users will meet.

EXTRA 5.3.6 You can describe what a rejected take-off is.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	5.3.1	5.3.2	5.3.3	5.3.4	5.3.5	5.3.6	5.2.1*
Remembering	1abc		2ab, 3				
Understanding	4abcd, 5a		6acdfg, 7a	8ab, 9a	9ef, 10bc	12a	
Using	7b	8cd, 9c	6be, 9b		9d, 10a	11b, 12bc	5b
Analysing						11a	7b

* You can find this learning objective in an earlier section.

Physicists categorize motion into various types. They first look at the speed: does it keep increasing, does it stay the same all the time, or does it decrease? Or, as a motorist might put it, picking up speed, driving steadily or braking?

CHANGING SPEED

In many sporting events, the speed changes during the event. Figure 1 gives an example: stroboscopic recordings of three moments during a time trial in the Tour de France.

- In figure 1a, the cyclist is just starting off. He is trying to pick up speed as quickly as possible from a stationary start. This kind of motion, in which the speed keeps increasing, is called **acceleration**.
- In figure 1b, the cyclist is going at a constant speed along a flat road. The cyclist covers the same number of metres every second. This is called **uniform motion**.
- In figure 1c, the cyclist is braking after he has passed the finishing line. His speed is therefore decreasing. A movement in which the speed keeps decreasing is called a **deceleration**.

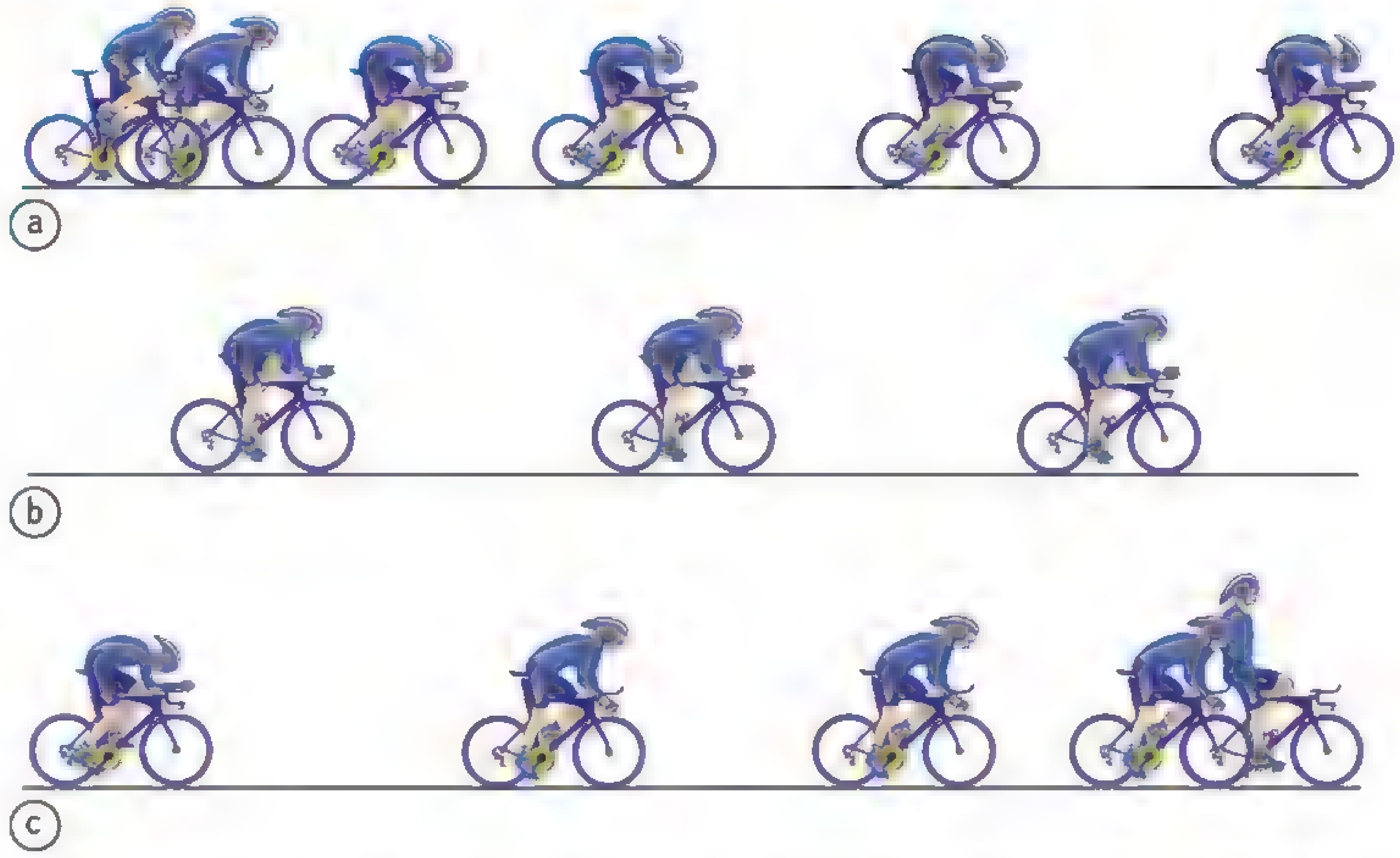


figure 1 A time trial: the cyclist's motion is first acceleration, then uniform motion and then deceleration.

UNIFORM MOTION

The speed does not change during uniform motion: it is constant throughout. If you know the average speed, you immediately know what the speed was at every moment during the motion. So, for a uniform motion:

$$v = v_{avg} = \frac{s}{t}$$

where:

- v is the speed in metres per second (m/s);
- v_{avg} is the average speed in metres per second (m/s);
- s is the distance travelled in metres (m);
- t is the time in seconds (s).

Figure 2 gives the (x,t) diagram for a cyclist who is going at a constant speed of 5.0 m/s. A straight line in an (x,t) diagram means it is a uniform motion. The (v,t) diagram of this cyclist is drawn in figure 3. A uniform motion is still shown as a straight line in a (v,t) diagram, but it now runs horizontally. After all, the speed isn't changing.

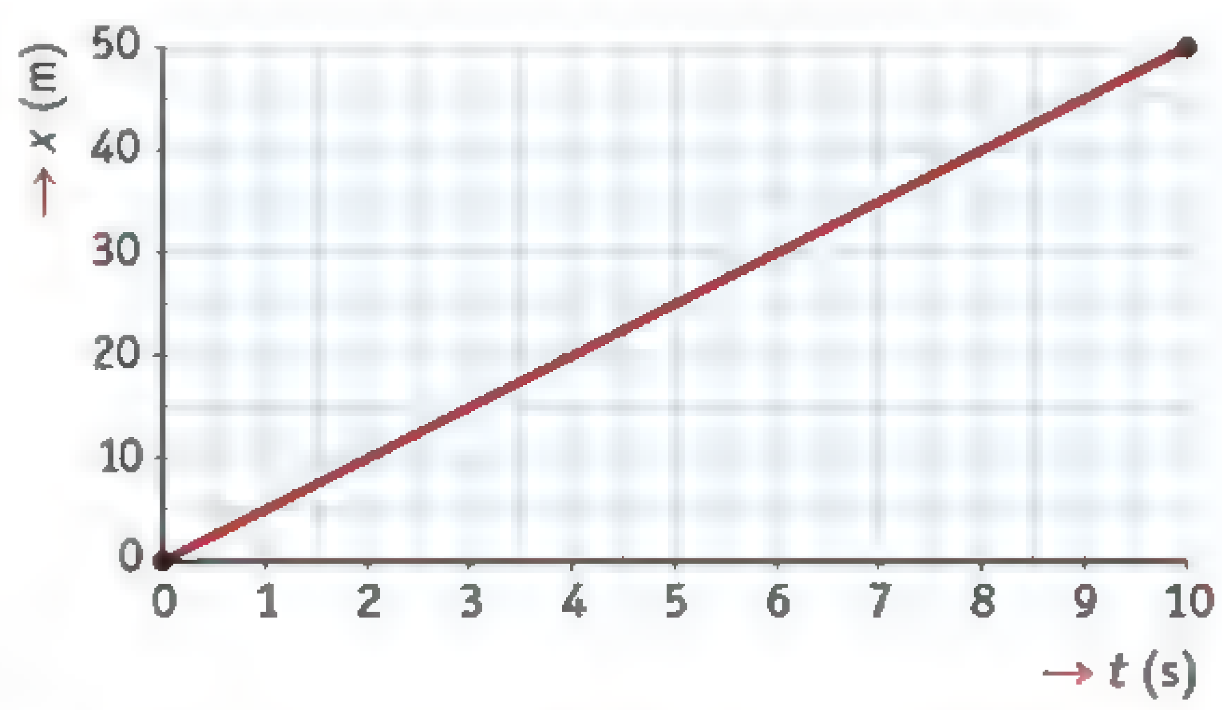


figure 2 The (x,t) diagram for a uniform motion.

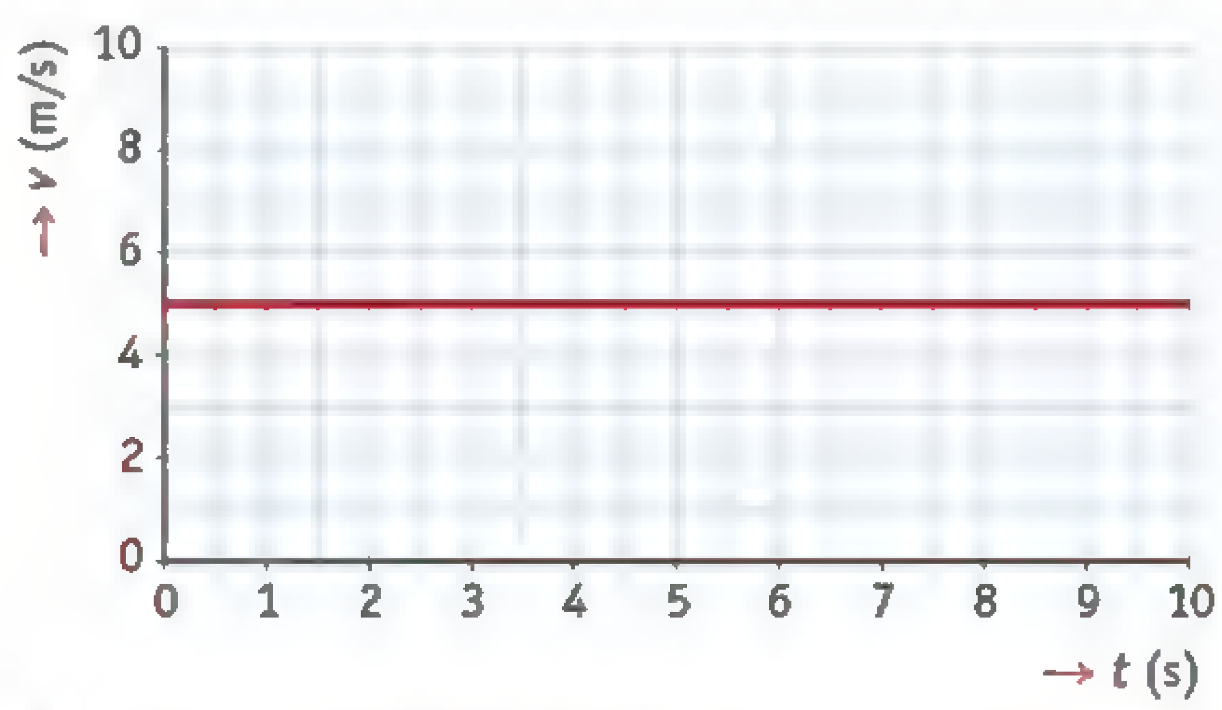


figure 3 The (v,t) diagram for a uniform motion.

EXAMPLE EXERCISE 1

Helen has made a stroboscopic photo of a toy car that is moving uniformly (figure 4).
The time between two light flashes is 0.4 s.
Calculate the speed of the car.

given $t = 8 \times 0.4 = 3.2$ s
$s = 82 - 2 = 80$ cm

required $v = ?$

working $v = \frac{s}{t} = \frac{80}{3.2} = 25$ cm/s $= 0{,}25$ m/s

figure 4 A stroboscopic photograph of a toy car.

ACCELERATING AND DECELERATING MOTION

If an object is accelerating, it covers increasing distances in successive equal time intervals. You can see this in a stroboscopic photo of the motion: the distances between successive pictures get greater. If you draw the (x,t) diagram for this kind of motion, you get a curved line that keeps going up more steeply (figure 5). The (v,t) diagram of this motion is shown in figure 6. It is a straight line that goes up at an angle. That is because the speed is increasing.

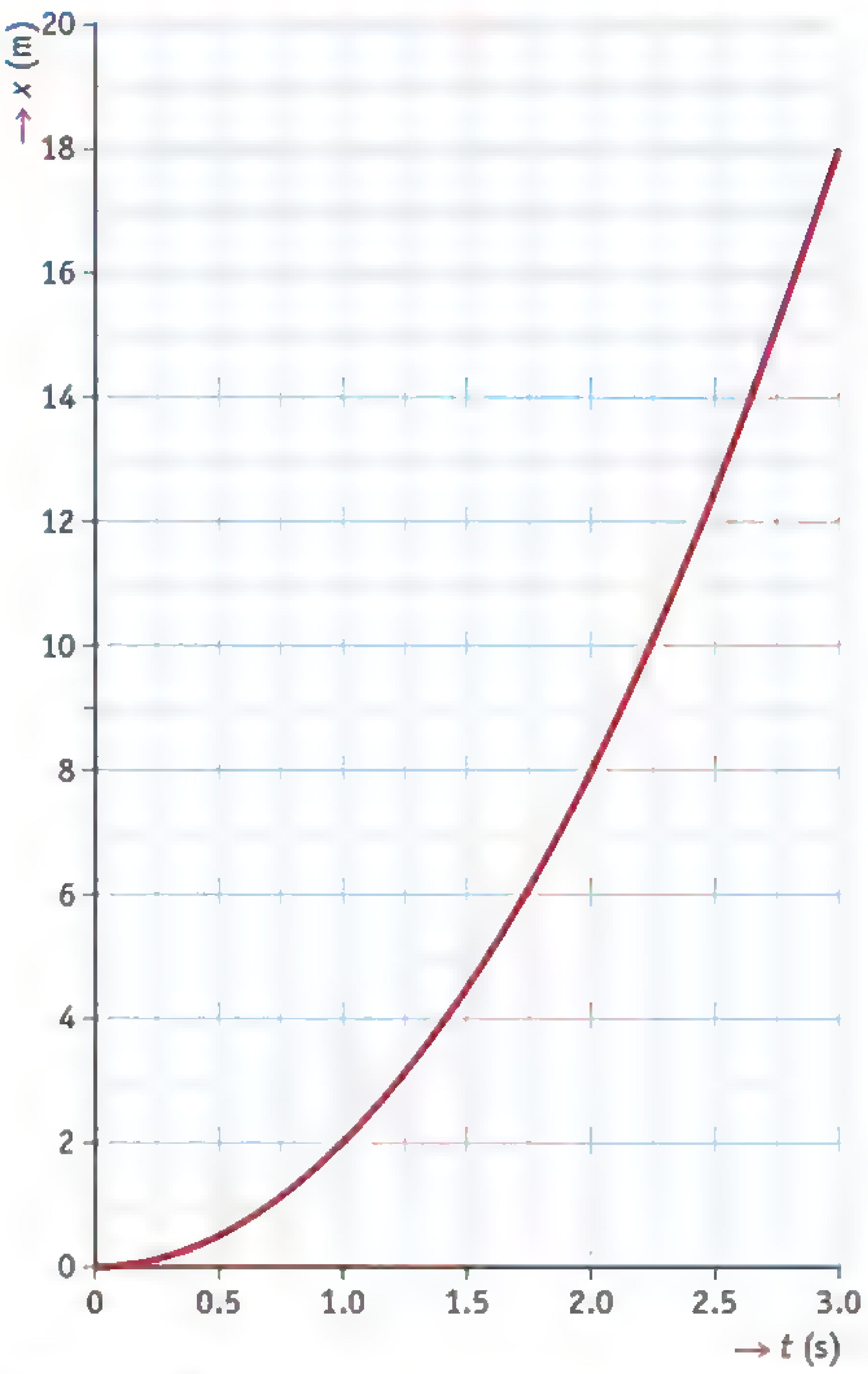


figure 5 The (x,t) diagram for an accelerating motion.

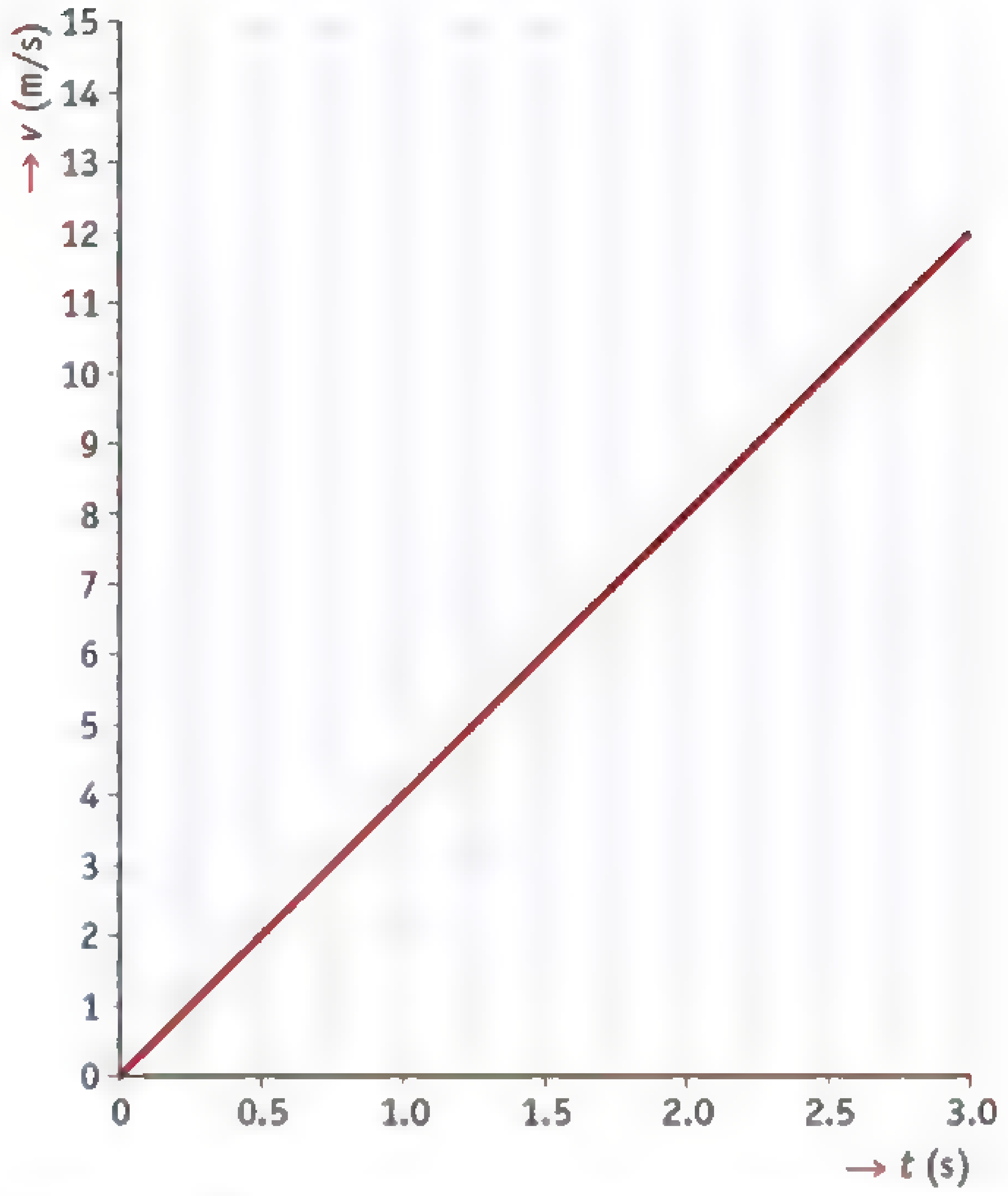


figure 6 The (v,t) diagram for an accelerating motion.

Figure 7 gives the (x,t) diagram for a decelerating motion. In this kind of motion, you see the opposite effect to an accelerating motion: the distances that the object travels in a given time keep getting less. You can also see that in the (x,t) diagram: the graph is a curve that keeps going up more shallowly.
The (v,t) diagram of this motion is shown in figure 8. It is a straight line that goes down at an angle. That is because the speed is decreasing.

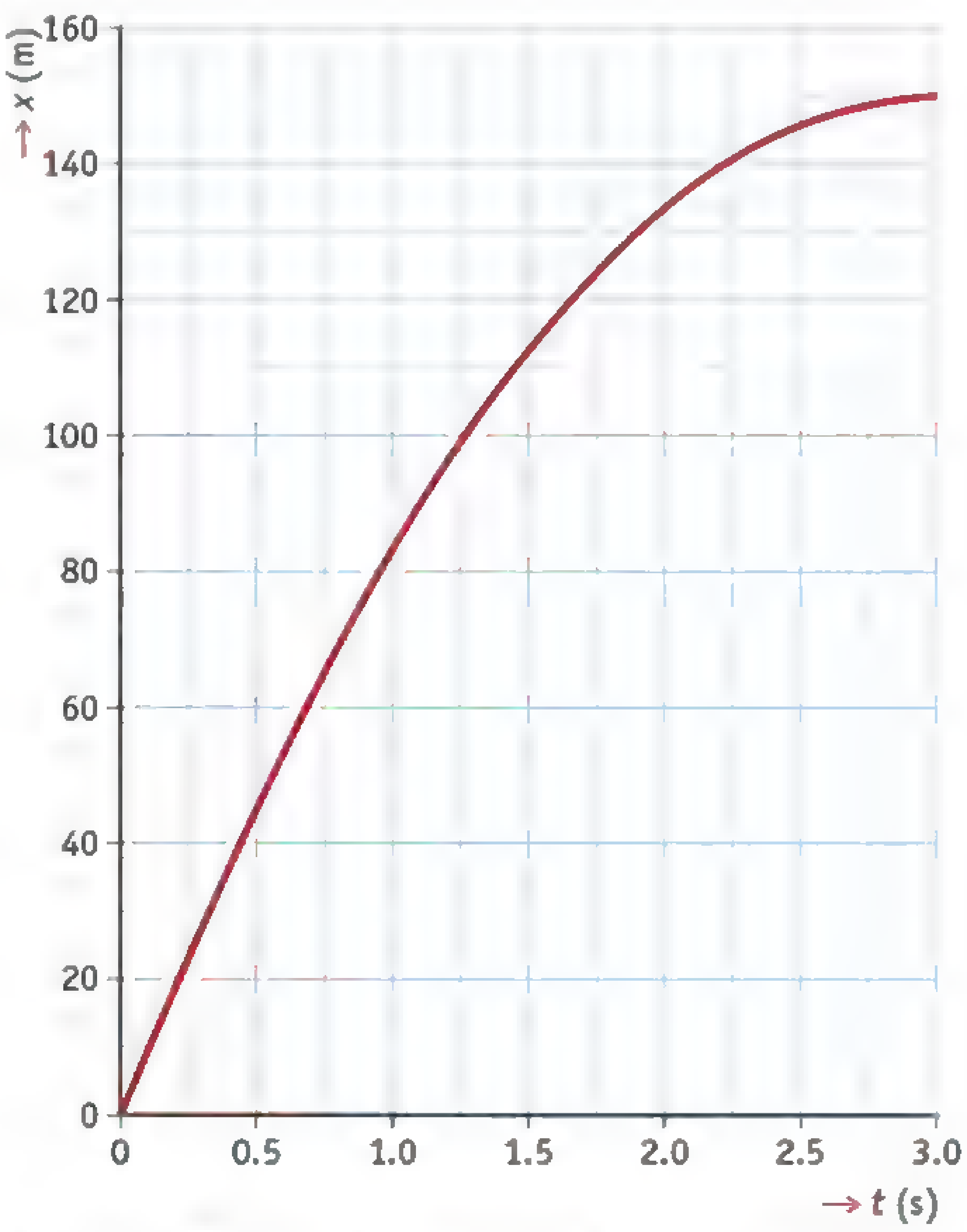


figure 7 The (x,t) diagram for a decelerating motion.

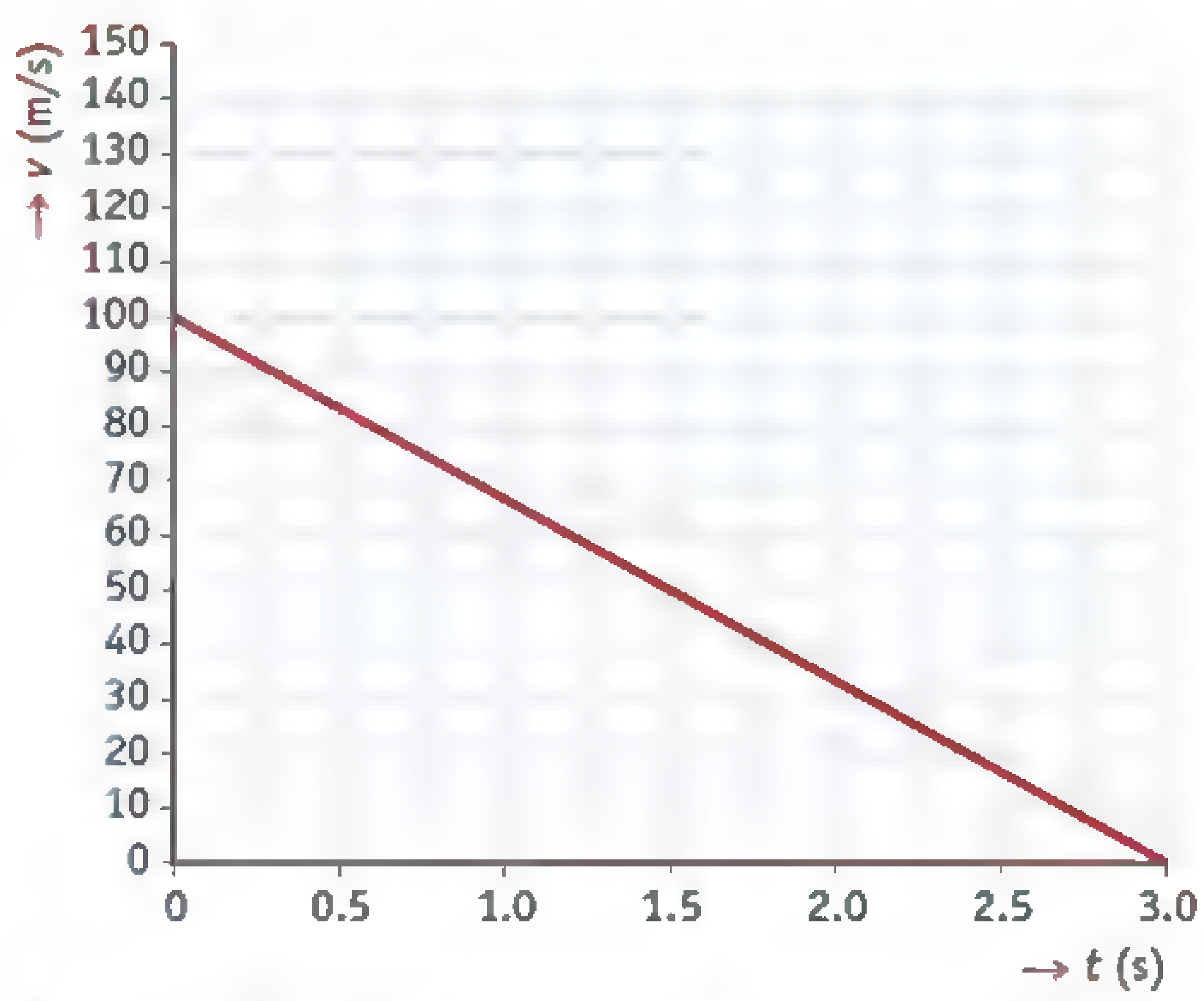


figure 8 The (v,t) diagram for a decelerating motion.

ONCOMING TRAFFIC AND OVERTAKING

On most roads, there is traffic in two directions. You often come across someone who is going in the opposite direction. Every now and then you will also be overtaken by someone else. Sometimes it can be useful to record these types of motion in a single (x,t) diagram. This lets you work out when and where two road users will meet.

EXAMPLE EXERCISE 2

Brian leaves on his bicycle at $t = 0$ s from the mailbox in front of his home, heading towards the shop 40 m further along. His speed is 3.0 m/s. At the same moment, Lisa leaves the shop on foot, walking towards Brian (figure 9). Her speed is 1.0 m/s. Work out when and where they will meet.

Lisa and Brian are moving along the same path. Their motions have been drawn in on the (x,t) diagram in figure 10. Graph I shows Brian's motion. It starts at 0 m. Graph II shows Lisa's motion. It starts at 40 m. The coordinates of the point where the two graphs intersect are $t = 10$ s and $x = 30$ m. Lisa and Brian therefore meet 30 m from the mailbox at time $t = 10$ s.

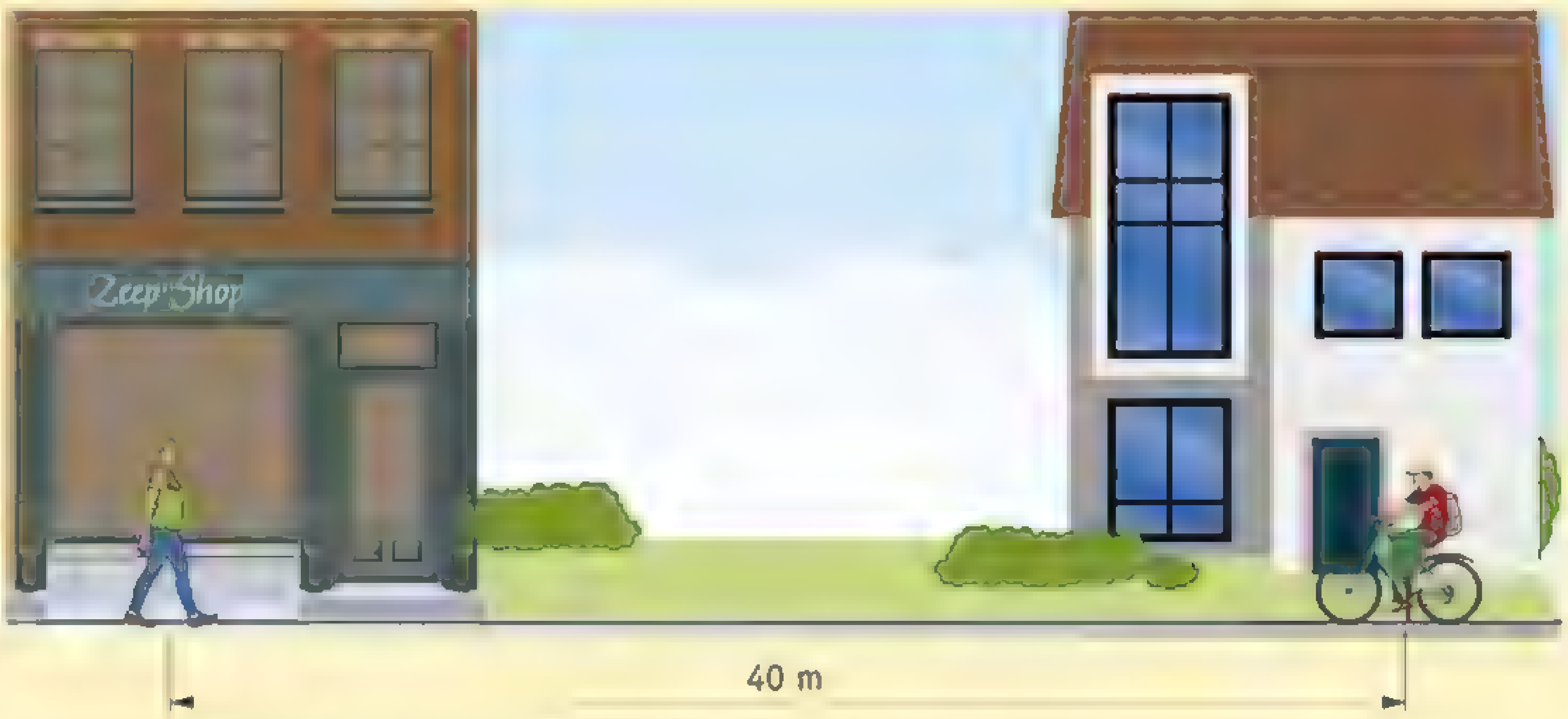


figure 9 Where do Lisa and Brian meet?

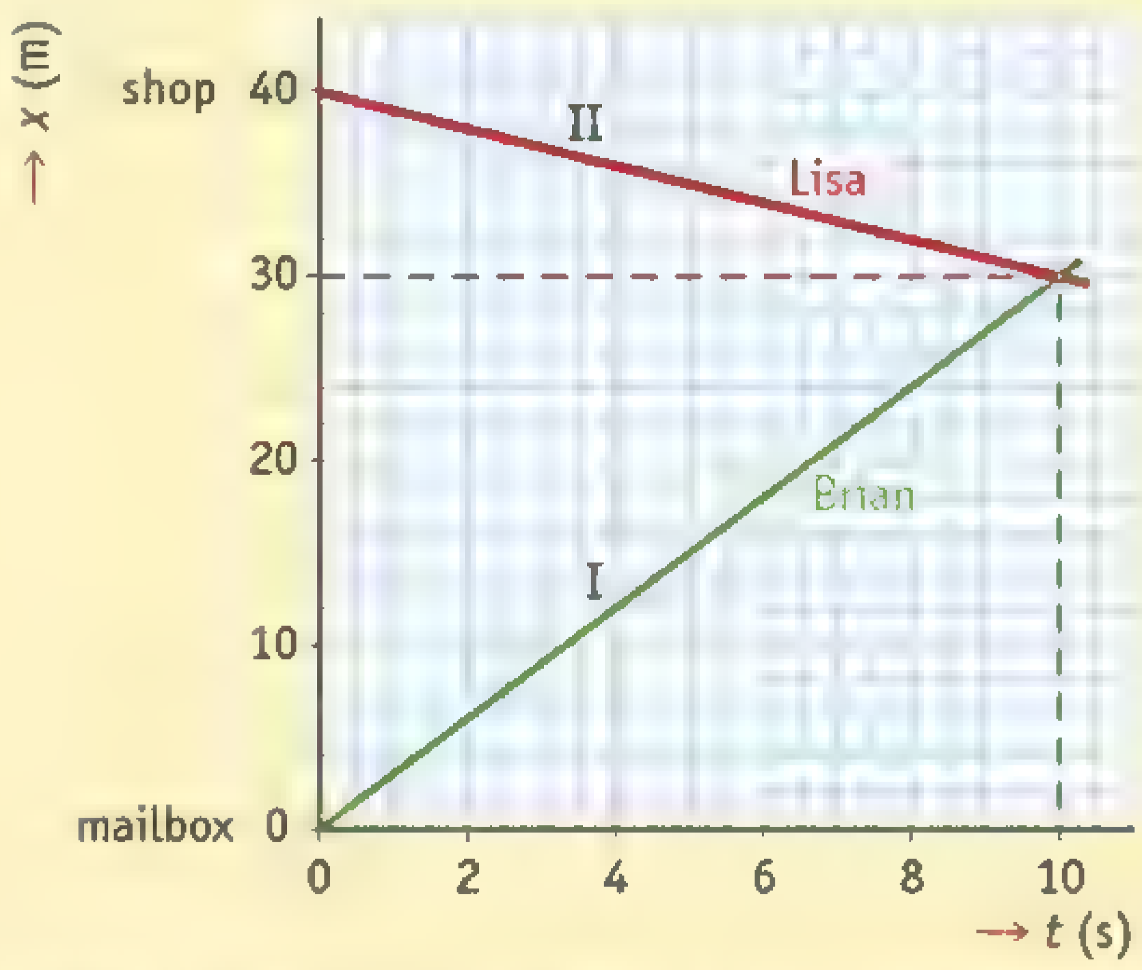


figure 10 The (x,t) diagram of the encounter.

Practice the concepts using the *Flash cards*.

EXTRA REJECTED TAKE-OFF

If it is to be able to take off, an aircraft has to get up to a speed of about 250 km/h in just a short time (figure 11). Fortunately, aircraft almost always manage to get up off the runway successfully. Just occasionally, the crew in the cockpit may decide to abort the plane's take-off. This is known as a "rejected take-off".

They may do that for instance because one of the engines is stuttering or because they notice some other technical defect. The pilots then have to decide very quickly whether or not they will try to make the plane take off. If they aren't going to do that, the take-off will have to be aborted at high speed. That can be risky. Because of the high speed, the plane will still cover several hundred metres before stopping, even at maximum braking. The runway may then be too short.

figure 11 An aircraft on the runway.

COURSE MATERIAL

1 What is the name for a motion:

a in which the speed keeps increasing?
b in which the speed does not change?
c in which the speed keeps decreasing?

2 You need graph paper for this exercise.
Three types of motion were described in Exercise 1.

a Draw the (x,t) diagrams for these motions.
b Label each diagram to show what kind of motion it is.

3

In figure 12, you can see the (v,t) diagrams of three movements.
For each diagram, write down what kind of motion it is.

- diagram A: *acceleration / uniform motion / deceleration*
- diagram B: *acceleration / uniform motion / deceleration*
- diagram C: *acceleration / uniform motion / deceleration*

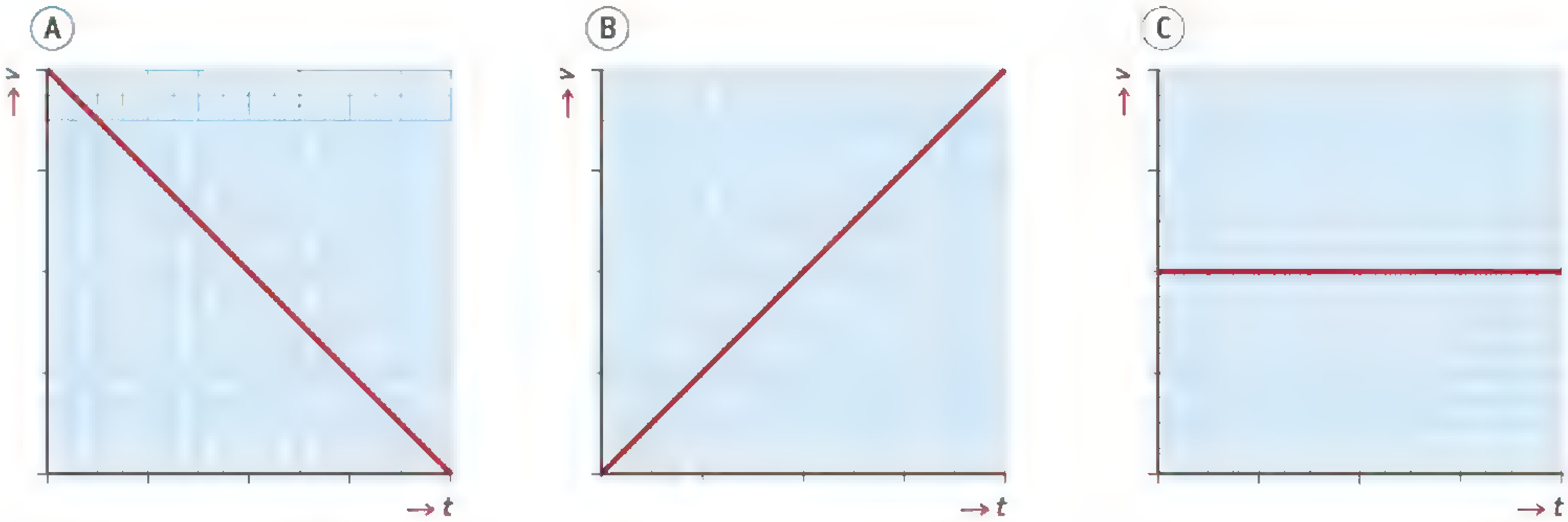


figure 12 The (v,t) diagrams of three movements.

IN PRACTICE

4

For each of the following movements, state whether it is an acceleration, uniform motion or deceleration.

a The motion of your bicycle if you are moving uphill without pedalling.
acceleration / uniform motion / deceleration

b The motion of an express train during most of the journey.
acceleration / uniform motion / deceleration

c The motion of a sprinter during the first second of the 100 metres.
acceleration / uniform motion / deceleration

d The motion of a car that is braking for a pedestrian who is crossing the road.
acceleration / uniform motion / deceleration

5

A moped is leaking one drop of oil each second. Figure 13 shows part of the trail of oil drops that it has left. The first oil drop fell at A. The distance between points A and B is 20 m.

a How can you tell that the moped was accelerating between A and B?

b Calculate the average speed of the moped between A and B.

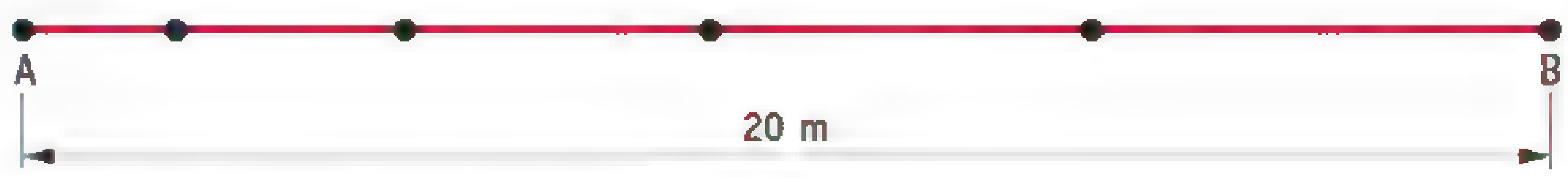


figure 13 A trail of oil drops.

6

Judith is cycling to school from home. Figure 14 gives the (x,t) diagram for her motion. Which part of the diagram corresponds to which of the following descriptions?

a She waits at a red traffic light. ....

b She cycles at a steady speed of 4.0 m/s. ....

c She brakes when a traffic light goes red. ....

d She gets onto the bicycle and cycles off from home. ....

e She cycles at a steady speed of 6.0 m/s. ....

f She cycles off when the traffic light goes green. ....

g She brakes and gets off the bike when she gets to school. ....

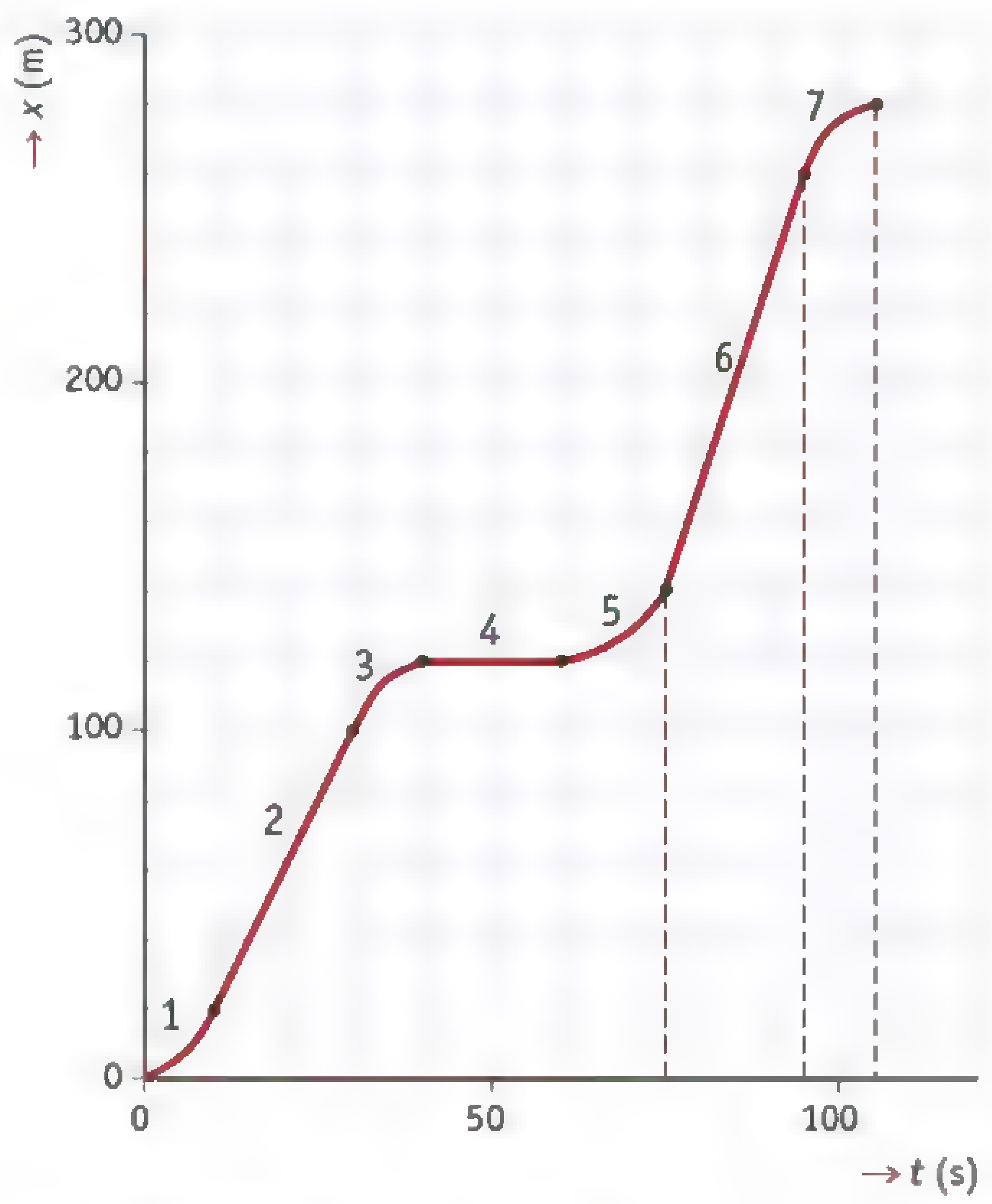


figure 14 The (x,t) diagram for Judith.

7

Examine the (x,t) diagram in figure 14 again.

a In which parts of the diagram:

- is the motion an acceleration? *part 1 / part 2 / part 3 / part 4 / part 5 / part 6 / part 7*
- is the motion uniform? *part 1 / part 2 / part 3 / part 4 / part 5 / part 6 / part 7*
- is the motion a deceleration? *part 1 / part 2 / part 3 / part 4 / part 5 / part 6 / part 7*

b Calculate Judith's average speed in km/h.

8

Figure 15 gives the (x,t) diagram for a parachute jump.

a What height did the parachutist jump from?

b At what moment did the parachute open?

c Between which points in time:
- is the motion an acceleration?
- is the motion a deceleration?
- is the motion uniform?

d Between which moments was the parachutist moving fastest?

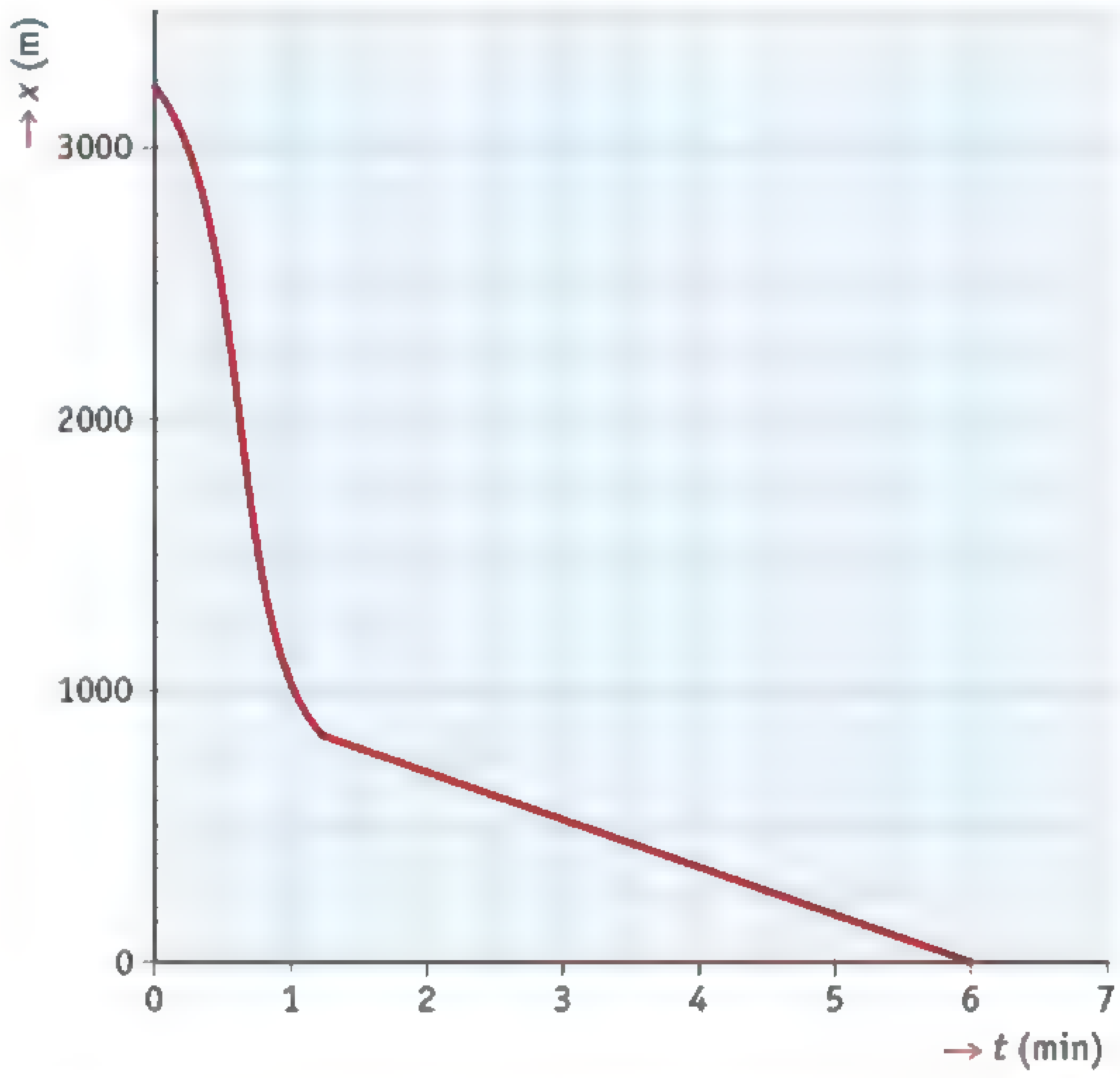


figure 15 The (x,t) diagram of a parachute jump.

9

Kim and Amber are in the same class. Kim goes past Amber's house when she cycles to school. Figure 16 shows the (x,t) diagram for Kim and Amber's journey to school.

a How many metres away from Kim is Amber when she starts?

b Who cycles faster? How can you tell?

c Calculate the speeds of both pupils.

d Kim and Amber carry on at the same speeds until one overtakes the other. Draw the graph of their motions in figure 16.

e Add a point marked with the letter 'P' where Kim and Amber meet up.

f After how many minutes does this happen?

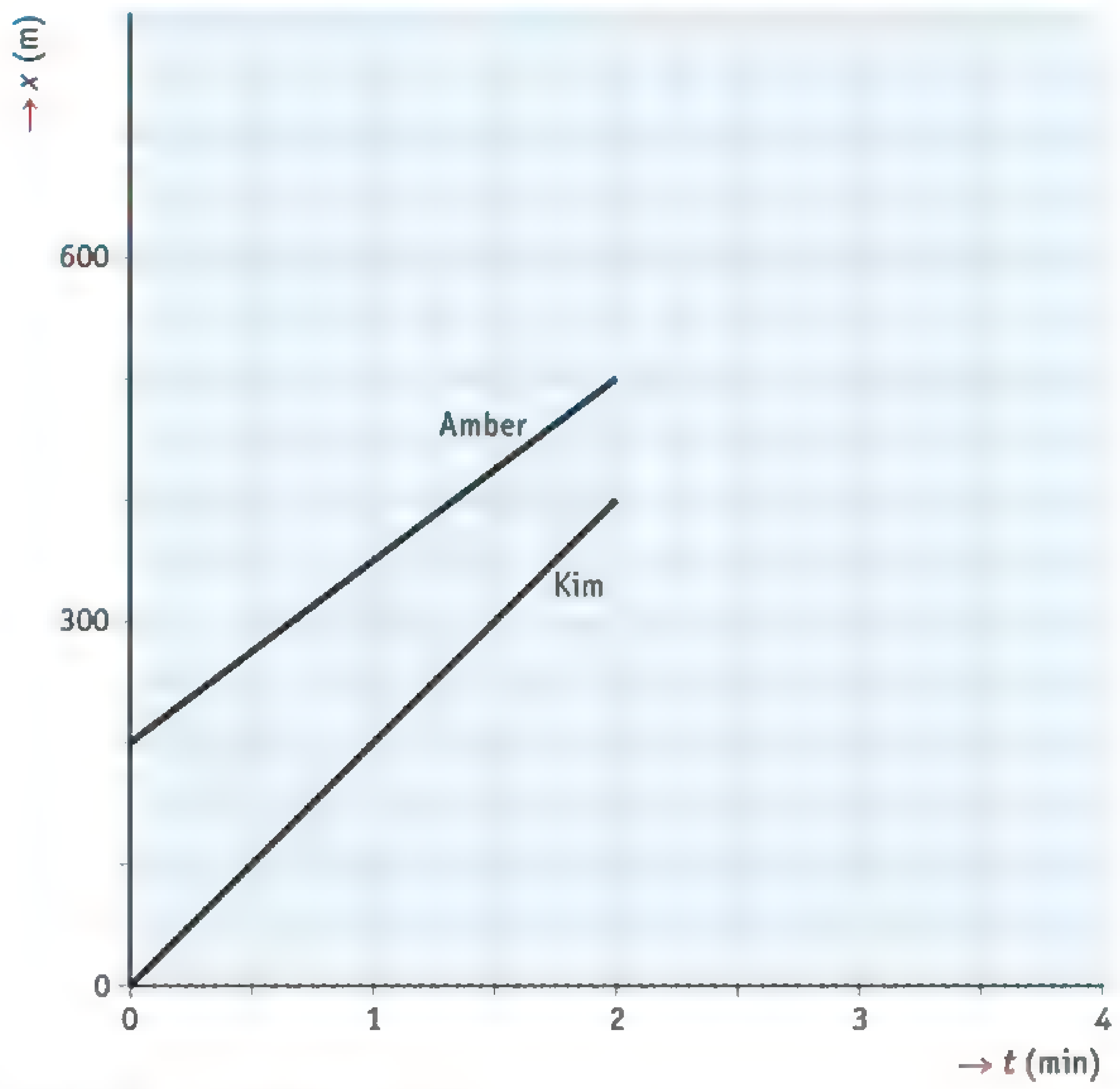


figure 16 An (x,t) diagram.

★ 10

Robin and Louise are driving around on their motorbikes. Robin is waiting at a traffic light when Louise comes along. When the light turns green, Robin starts moving. At the same time, Louise goes past him on her motorbike. At that moment, Louise's speed is a steady 54 km/h.

a Draw the graph for Louise's motion in figure 17.

b At what point in time will Robin pass Louise?

c Read off from the graph how many metres from the traffic light Robin passes Louise.

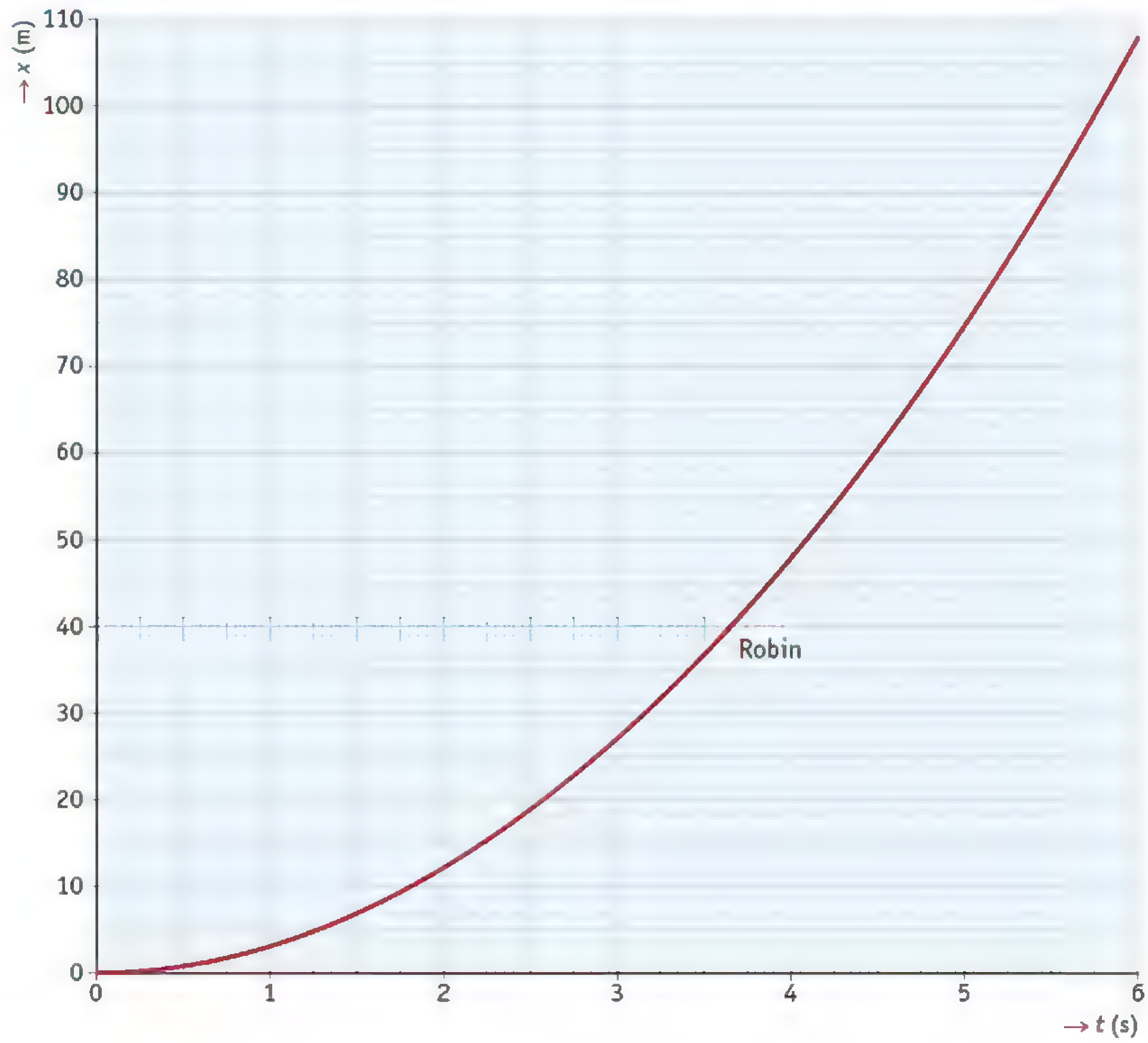


figure 17 The (x,t) diagram for Robin and Louise.

Test what you know with *Test yourself*.

EXTRA REJECTED TAKE-OFF

11 A take-off on the runway can only be aborted if the speed has not yet increased beyond a certain speed. In aviation, that speed is called 'v_1' and it is recalculated for every time a plane takes off. This speed v_1 depends on the plane's mass, among other things.

a Write down another factor that this speed will depend on.

b Will the value of v_1 be smaller or larger for a heavily loaded plane than for one of the same type that is taking off unloaded?

12 A plane makes an emergency stop on the runway from a speed of 270 km/h. The pilot manages to bring the aircraft to a standstill in 24 s.

a Convert the speed to m/s.

b During the emergency stop, the speed decreases steadily until the plane is stationary. Calculate the average speed of the plane during the emergency stop.

c The length of runway remaining at the moment the pilot begins to brake is 1.0 km. Use a calculation to work out whether the plane comes to a standstill before the end of the runway.

4 Braking and collisions

LEARNING OBJECTIVES

5.4.1 You can explain what the braking distance is and what it depends on.

5.4.2 You can use a graph to explain the relationship between the initial speed and the braking distance.

5.4.3 You can explain what is meant by the reaction time and the reaction distance.

5.4.4 You can calculate the stopping distance of a car.

EXTRA 5.4.5 You can write down the safety features in a car.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	5.4.1	5.4.2	5.4.3	5.4.4	5.4.5	5.1.4*
Remembering	1ac, 2ab, 3c	1b	1d, 3ab	3d	11	
Understanding	4abcde, 5b	6a	5a		12ab	
Using			6b, 9a, 10a	6c, 10b	12c	8a
Analysing		10c	9b	7, 8b, 10d		

* You can find this learning objective in an earlier section.

If you are a motorist, you must always make allowances for the traffic around you. In the event of an emergency, you have to be able to stop in time, even if the road is slippery and your car is heavily loaded. Good drivers will therefore adjust their speed and stay further behind the vehicle in front of them if the situation demands it.

THE BRAKING DISTANCE

When a car's brake pedal is pressed, the car keeps decelerating until it comes to a standstill. During that deceleration, the car will still cover a certain distance. This distance is known as the braking distance. The longer the braking distance, the greater the risk of an accident.

The braking distance depends on:

1 *The initial speed*
The initial speed is the speed at the moment the car begins to brake. The greater the initial speed, the greater the braking distance.

2 *The (total) mass of the car*
The greater the mass of the car, the longer its braking distance will be. A fully loaded truck will have a greater braking distance than an empty one.

3 *The braking force*
The harder you push down on the brake pedal, the greater the braking force will be and the shorter that will make the braking distance (as long as the car does not start to skid).

INITIAL SPEED AND BRAKING DISTANCE

Figure 1 shows how long the braking distance is for a family car at various initial speeds. The data in the graph comes from braking tests, using the same car throughout. The braking was just as hard every time as well. Only the initial speed was different every time.

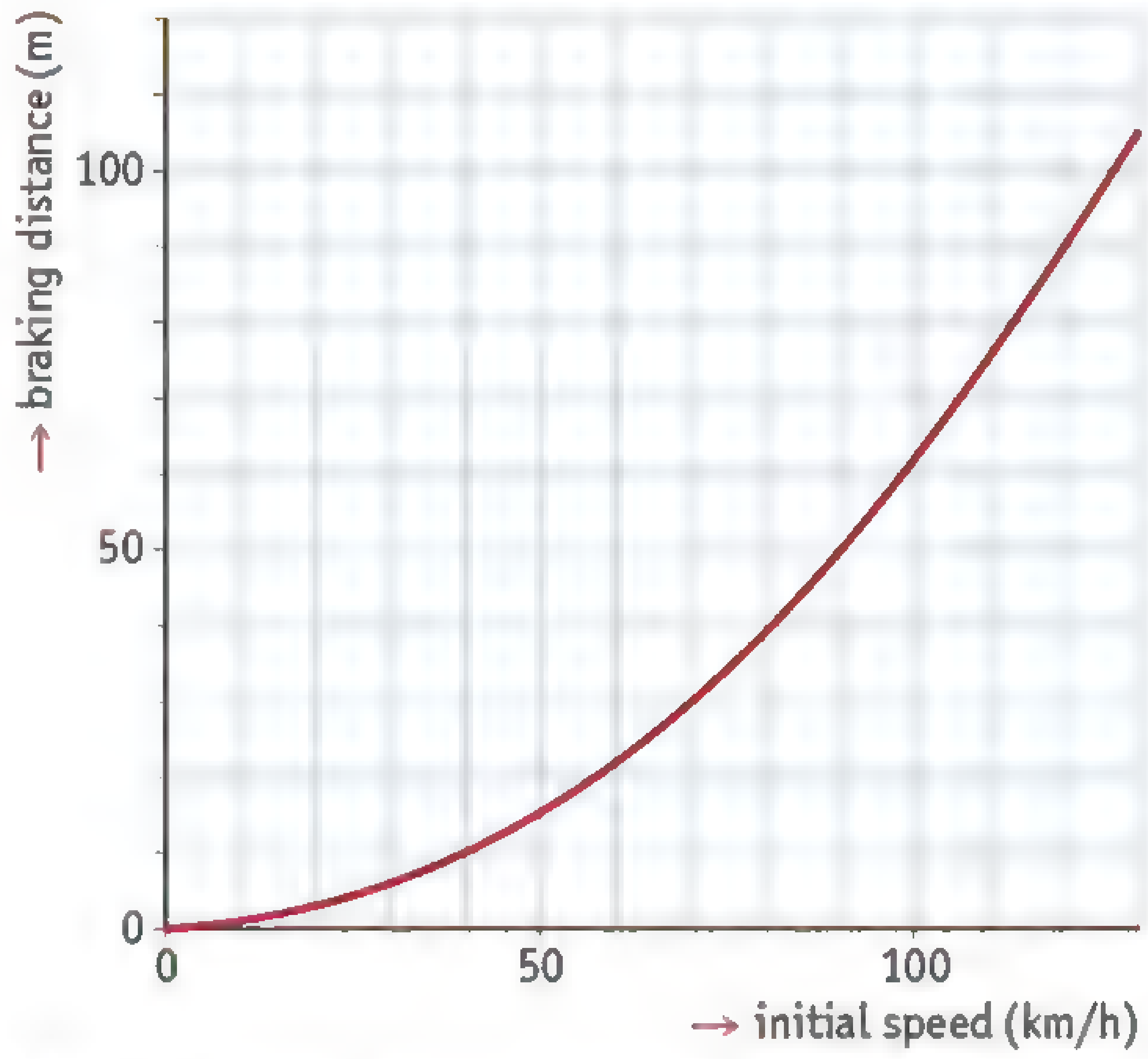


figure 1 Braking distance and initial speed.

The graph shows that the braking distance increases rapidly for greater initial speeds of the car. To be precise:

If the speed is *n* times greater, the braking distance becomes n^2 times longer.

If the speed doubles from 40 to 80 km/h, then the braking distance is four (2^2) times as long: it increases from 10 m at 40 km/h to 40 m at 80 km/h.

The graph in figure 1 applies for normal circumstances: brakes and tyres that are in good condition, a normal road surface and dry weather. If the brakes are worn, the tyres don't have much tread or the road surface is slippery because of snow or ice, the driver cannot brake so hard. The braking force is then less and the braking distance correspondingly longer – sometimes much longer (figure 2).

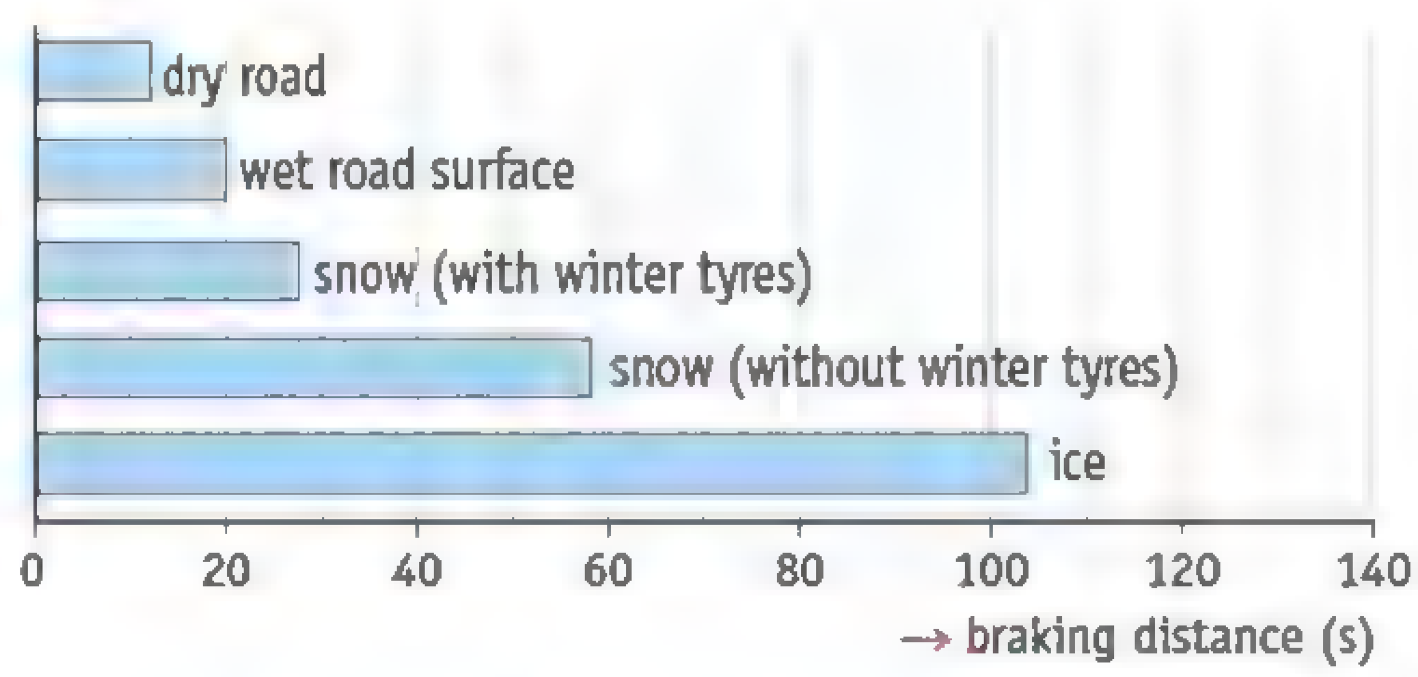


figure 2 The braking distance of a car in various weather conditions.

EXAMPLE EXERCISE 1

If a car is travelling at 40 km/h (v_1), the braking distance (under normal circumstances) is 10 m (s_1).
What is the braking distance (s_2) if the car is going at 120 km/h (v_2)?

given v_1 = 40 km/h
v_2 = 120 km/h
s_1 = 10 m

required s_2 = ?

working v_2 is 3× greater than v_1, so n = 3
s_2 is therefore $n^2 = 3^2 = 9$ × longer than s_1
The braking distance s_2 is therefore 9 × 10 = 90 m.

THE MASS AND THE BRAKING DISTANCE

The braking distance is affected by the mass as well as the (initial) speed. The more heavily a car or bicycle is loaded, the longer the braking distance will be. You will notice that for instance if you have someone else sitting on the back of your bike. Even if you brake just as hard as usual, it will take longer before you are stationary if someone is sitting on the back (figure 3).

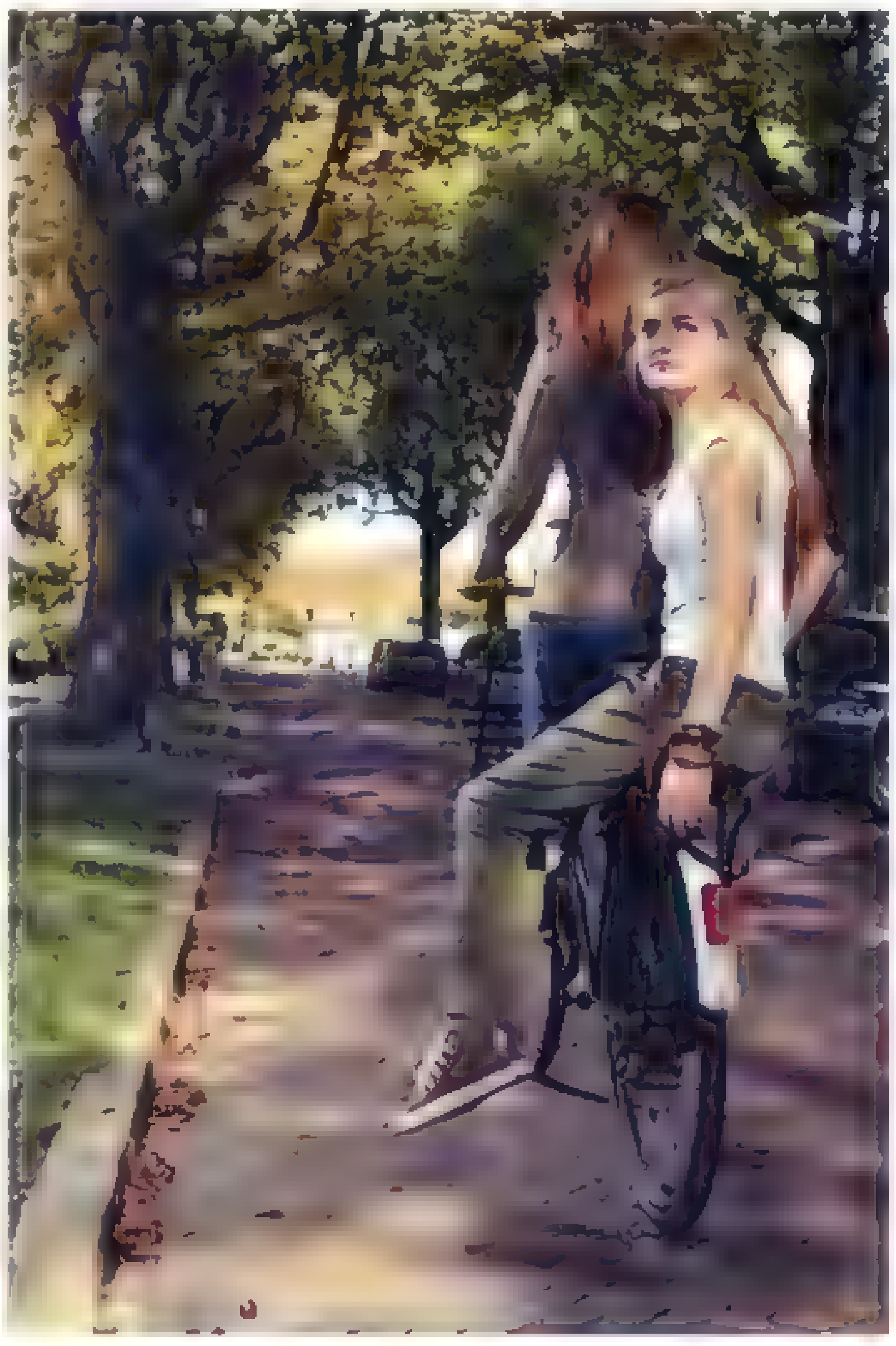


figure 3 The mass is greater if someone is sitting on the back, and so is the braking distance.

Many people go on holiday for the summer in a heavily loaded car. The braking distance of their car is then longer than they are used to. They will hopefully allow for that in their driving, for example by going more slowly, particularly when the roads are busy. This lets them shorten the braking distance, which would otherwise have become too long, back down to a safe value.
You should also keep a greater distance away from the car in front of you on the motorway if your car is heavily loaded. If something unexpected happens, you will then be less likely to drive into the vehicle in front. Maintaining a greater distance is also a good idea if it is raining or snowing. That helps reduce the chance of an accident.

REACTION TIMES

EXP. 1

If a child runs in front of a car, the driver will brake. But it is impossible for the driver to react instantly: it always takes a little time before the brake pedal is pressed and the brakes are applied. The time between seeing the hazard and the brakes being applied is called the **reaction time.**

The reaction time is normally between 0.7 and 1.0 seconds. If you are not alert or if you are tired, though, you react quite a bit more slowly. Using alcohol, drugs and some medicines also makes the reaction time longer.

The overall distance that a car needs to come to a halt – the **stopping distance** – is therefore more than just the braking distance. You also have to include the distance that the car travels during the reaction time: the **reaction distance** (figure 4). In other words,

stopping distance = reaction distance + braking distance

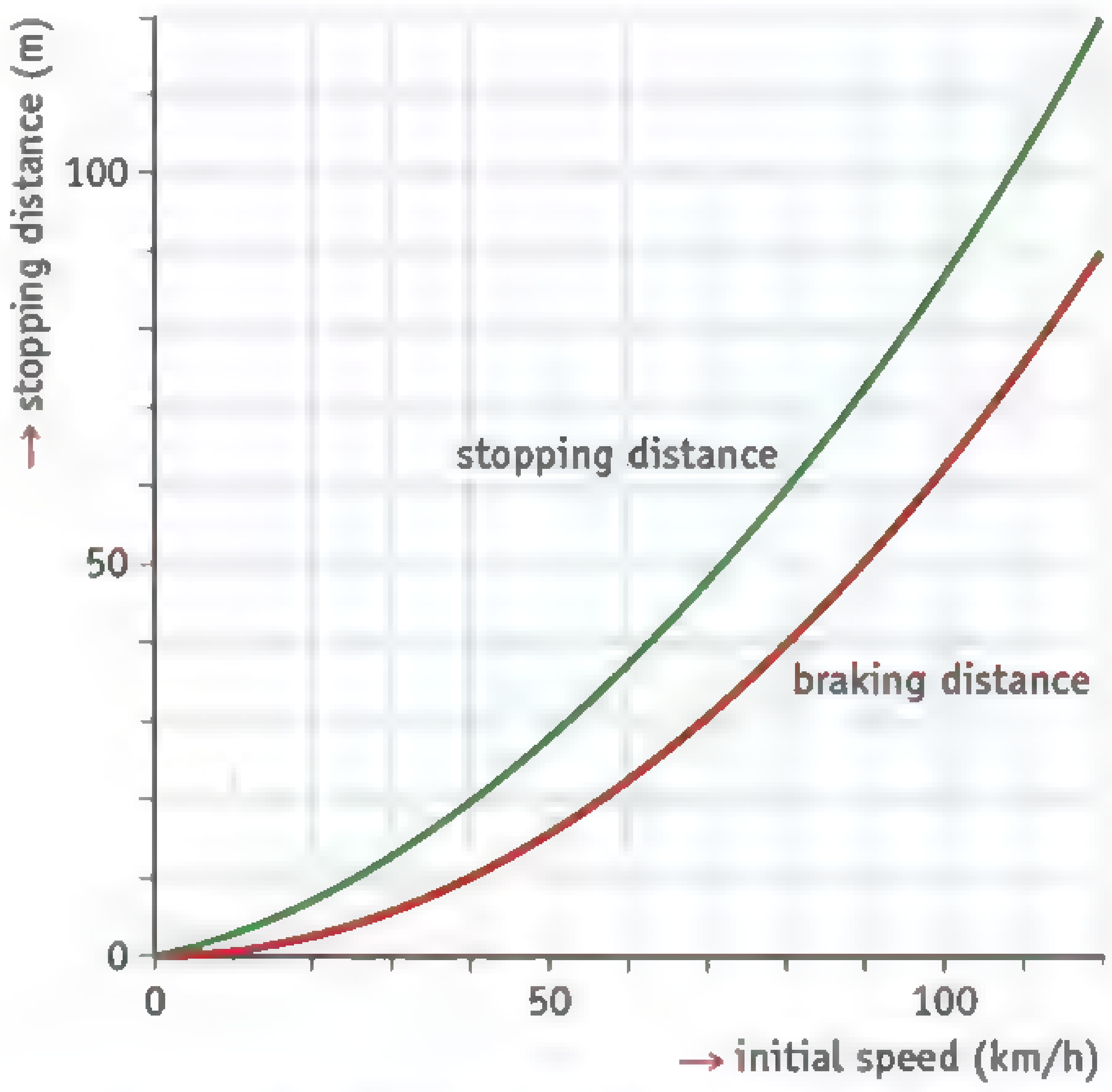


figure 4 The stopping distance is greater than the braking distance.

EXAMPLE EXERCISE 2

Jasmine is driving at 45 km/h along a minor road when she suddenly has to brake for a dog that runs across the road. Her reaction time is 0.8 s.
Determine the stopping distance. You can read the braking distance from figure 1.

given — for the reaction distance:
v = 45 km/h = 12.5 m/s
t = 0.8 s
for the braking distance:
According to figure 1, the braking distance is 12 m (at 45 km/h).

required — stopping distance = ?

working — reaction distance: $s = v \cdot t = 12.5 \times 0.8 = 10$ m
stopping distance = reaction distance + braking distance
= 10 + 12
= 22 m

Practice the concepts using the *Flash cards*.

EXTRA PROTECTION AGAINST COLLISIONS

When a car collides with something, it stops pretty much instantly. The 'braking distance' in a collision is very short and the impact experienced by the people inside is considerable. To protect the occupants, the 'braking distance' must be made as long as possible when there is a collision. There are various ways of ensuring this.

Cars are made so that the front end of the vehicle concertinas up in a collision. This collapsing section is called the crumple zone. It makes the 'braking distance' for the driver and passenger several tens of centimetres longer. The driver and passengers are safe inside the cage structure, the part of the car that is not easily deformed (figure 5).

figure 5 The crumple zone is collapsed like a concertina, but the cage structure hardly deforms at all.

The safety belts (seatbelts) make sure that the passengers decelerate at the same rate as the car. Without a seatbelt, the driver might for example only start decelerating when his head hit the windscreen. Besides that, the seatbelts stretch a little if the car is involved in a collision. That also increases the 'braking distance' for the people inside. An airbag has the same function as a seatbelt but has more 'give' in it (which means that the 'braking distance' will be a bit longer).

COURSE MATERIAL

1 Answer the following questions.

a What three factors determine a car's braking distance?
b What relationship is there between the speed of a car and its braking distance?
c How does your braking distance change if you take a passenger on the back of your bike?
d What factors might make someone have a slower reaction time than normal?

2 In poor conditions, a car can have a very long braking distance.

a Write down three examples of what might create poor conditions.
b In that kind of situation, the driver of the car should adapt their driving style. List two things that they can do to reduce the chance of accidents.

3 When a car driver sees that they have to stop, the car does not immediately start braking at that moment.

a What is the term for the time between seeing the hazard and the brakes being applied?

b What is the term for the distance the car travels during that time?

c What is the term for the distance the car travels while braking until it is stationary?

d How can you calculate the overall stopping distance?

IN PRACTICE

4 A car's braking distance is greater than normal in the five situations described below. State why for each of the situations.

a The driver has just picked up five passengers.
The mass is greater than normal. / The braking force is less than normal.

b The car's tyres no longer have any tread.
The mass is greater than normal. / The braking force is less than normal.

c The road is slippery because snow has just been falling.
The mass is greater than normal. / The braking force is less than normal.

d The brake linings are completely worn away.
The mass is greater than normal. / The braking force is less than normal.

e The roof rack and the boot are full of luggage.
The mass is greater than normal. / The braking force is less than normal.

5 Many accidents occur because a car is not able to come to a halt within a given distance. There are various possible causes of this.

a Which of these circumstances affect the reaction time?
worn tyres / fatigue / heavy rain / poor brakes / heavily loaded car / use of alcohol or drugs / excessive speed

b Which of these circumstances make the braking distance longer?
worn tyres / fatigue / heavy rain / poor brakes / heavily loaded car / use of alcohol or drugs / excessive speed

6 A family car is doing 120 km/h. The road conditions are normal.

a Read off the braking distance at this speed from figure 1.

b The driver of the car has a reaction time of 0.8 s.
Calculate what his reaction distance will be at 120 km/h.

c Calculate the overall stopping distance in this situation.

7 A motorist is driving in a built-up area at 40 km/h. He suddenly sees a child crossing the road 22 m in front of his car. His reaction time is 0.9 s.
Do the calculations to show that the car and child do not quite collide. Use figure 1 to read off the braking distance.

8 The government recommends that car drivers on through roads should 'maintain a distance of at least two seconds'.

a Two cars are driving on the motorway at a constant speed of 130 km/h, one behind the other. The second driver is sticking strictly to the 'two-second rule'.
Calculate the distance between the two cars.

b Why did the authorities choose to express the distance in seconds rather than metres?

9 Figure 6 shows the (x,t) diagram for a car that has to stop suddenly when a dog crosses in front of it. The reaction time is 0.75 s.

a Use the data from figure 6 to calculate what the initial speed of the car was.

b Use the diagram to help determine:

- the reaction distance;
- the stopping distance;
- the braking distance.

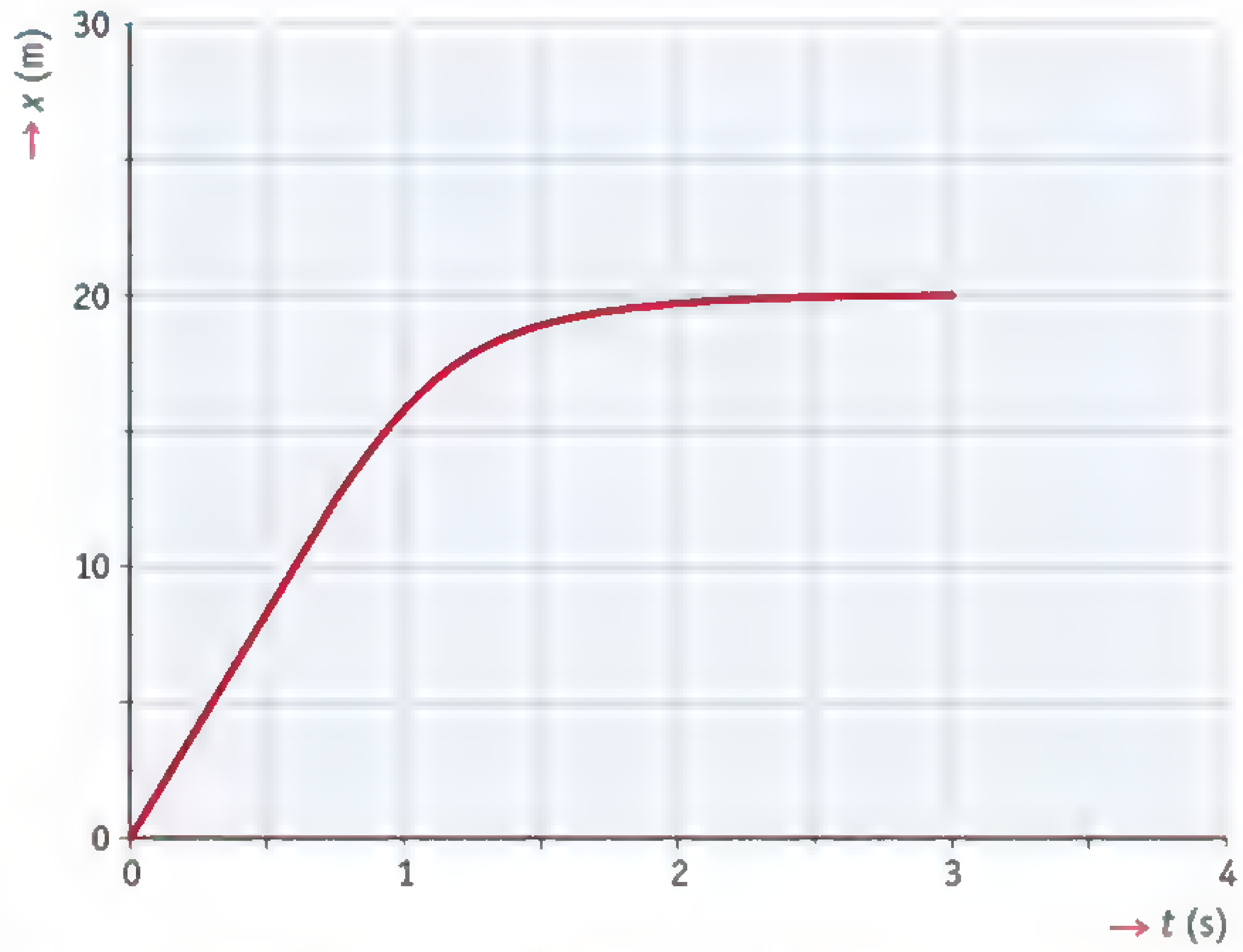


figure 6 The (x,t) diagram of a decelerating motion.

★ 10 More and more towns are introducing 30 km/h zones.

a A motorist has a reaction time of 1.0 s.
Calculate the reaction distance if a car driver is going at 30 km/h.

b The braking distance at 30 km/h is 5.3 m.
What is the stopping distance at 30 km/h?

c Calculate the stopping distance at 50 km/h. Show all your calculation steps.

d The car driver is going through a built-up area at 30 km/h when he sees a cyclist about to cross his path from the right, who he has to give way to, and he is then just able to stop in time. What speed would the motorist still have been doing as he crossed the cyclist's path if he was driving at 50 km/h? Explain exactly how you got to your answer.

Test what you know with *Test yourself.*

EXTRA PROTECTION AGAINST COLLISIONS

11 Cars contain a variety of features designed to stop the occupants from being injured if there is a collision.
List three such features.

12 In a collision, the front of a car is compressed by 50 cm. Besides that, the driver's seatbelt stretches sufficiently to let him move 30 cm forwards.

a What is the 'braking distance' for the driver?

b What would have happened to the driver if he had not been wearing a seatbelt? At what point would he then have started decelerating?

c The braking time in the collision (the time it takes for the occupant to come to a standstill) is 64 ms.
Calculate the average speed of the occupant (in km/h) during the collision.

Experiments

EXPERIMENT 1 MAKING A STROBOSCOPIC PHOTO

50 minutes

Introduction
Making a stroboscopic photo is often a good way of recording a motion. The nice thing about this kind of photo is that it summarizes the whole movement in a single image. Athletes can use this kind of photograph to find out exactly how they are executing a movement. That lets them discover where they can still improve.

Goal
In this experiment, you are going to be taking several stroboscopic photographs yourself.

Requirements
- ☐ stroboscope
- ☐ camera with an adjustable shutter time
- ☐ stand (tripod)
- ☐ darkened room with a dark background

Doing the experiment and writing it up
Sharing the work

Some of the class will be taking the pictures; these are the photographers. The other pupils will be taking turns to execute a movement; these are the test subjects.

Preparation

Instructions for the test subjects:
- Think up what movement you are going to carry out. Be creative and think of motions that will 'look good' on a stroboscopic photograph.
- Try out the movement. Be aware of safety, both for yourself and others.

Test runs and adjustments

Instructions for the photographers:
- Get the test subject to execute their movement. Determine how long the movement that is to be photographed actually takes.
- Set the height of the tripod so that the motion is neatly in the frame.
- Set the camera's shutter time so that the entire movement can be photographed.
- Set the stroboscope to a suitable rate, between 5 and 20 flashes per second.

Doing the work

Instructions for the photographers:
- Ask the person whose turn it is to get ready.
- Press the camera's shutter release and give the starting signal.
- Wait until the camera shutter has closed again.

1 View and assess the photograph.
 a Has the motion been clearly recorded?

 b Is the distance between the various images correct?

 c Was the shutter time correct – not too long or too short?

- Adjust the settings if necessary and take another photo. Otherwise, move on to the next test subject.

2 How does the photo change if the number of flashes per second is increased or decreased?

3 How does the photo change if the movement is executed more slowly?

4 How does the photo change if the shutter time is lengthened or shortened?

5 Make a distance-time diagram for the photos you have made.

EXPERIMENT 2 STUDYING MOTIONS

45 minutes

Introduction

If you want to study a motion, you start by recording it. You find out where the moving object is (the position) at several successive moments (the time). There are then various ways of processing the data.

Goal

You are going to determine the distances and times for five movements. You will then process that data to produce a distance-time diagram.

Requirements

- ☐ 6 to 10 stopwatches
- ☐ starting flag
- ☐ chalk
- ☐ a 10 m length of cord
- ☐ bicycle
- ☐ graph paper

Doing the experiment and writing it up

Preparation

- A track of 60 to 100 metres should be marked out at a suitable location, with a line chalked in every 10 metres (figure 1).
- One pupil stands at the start with the starting flag. One pupil stands at each 10-metre line with a stopwatch.

Doing the work

The measurements are made as follows each time:

- The starter brings the starting flag down to start the movement. All the stopwatches are started at that same moment.
- At the point when the walker/sprinter/cyclist passes a 10-metre line, the stopwatch at that marker is stopped.
- Each pupil with a stopwatch then writes down the time they measured.

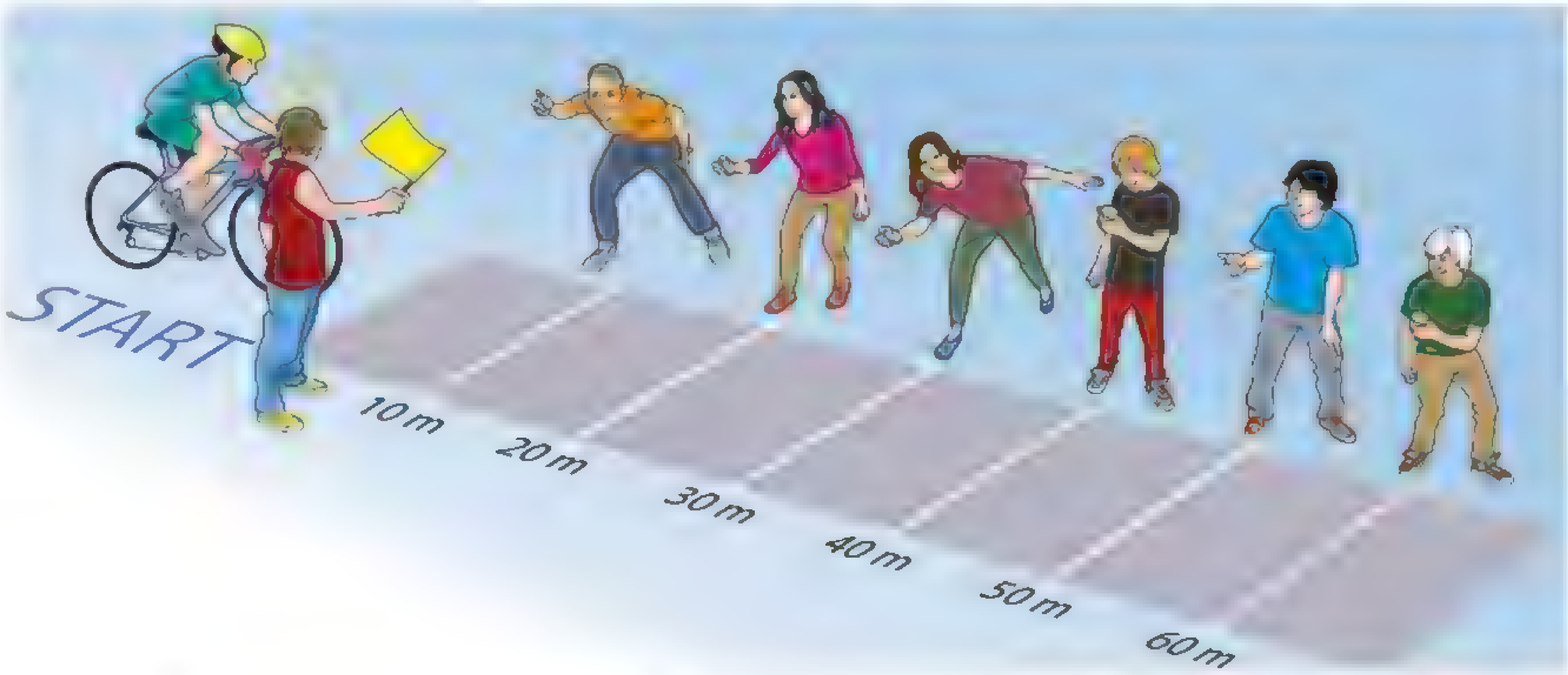


figure 1 The measurement setup for Experiment 2.

That will let you gather data for five movements:

- Pupil I walks at a normal pace.
- Pupil II sprints as fast as they can.
- Pupil III cycles at a gentle speed.
- Pupil IV cycles as fast as possible.
- Pupil V cycles as fast as possible with a second pupil on the back.

Writing up

- All the measurements are written on the board once the experiment is complete.

1 Write down all the measurements at the appropriate places in table 1.

table 1 The distance-time table for Experiment 2.

displacement (m)	I time (s)	II time (s)	III time (s)	IV time (s)	V time (s)
0					
10					
20					
30					
40					
50					
60					
70					
80					
90					
100					

2 Draw the distance-time diagrams for each motion on graph paper. Use a different colour for each.

- Answer the questions below after Section 3 has been discussed in class.

3 Compare your distance-time diagrams with the distance-time diagrams in Section 3.

a For which motion (or motions) is the speed roughly constant? How can you tell?

....

....

b For which motion (or motions) can you clearly see that there was an acceleration at the start? How can you tell?

....

....

4 Calculate the average speed for each motion, first in m/s and then in km/h.

....

....

....

EXPERIMENT 3 RECORDING MOTIONS WITH A TICKER TIMER

45 minutes

Introduction

A ticker timer is a device that draws dots on a strip of paper known as a ticker tape. You attach the ticker tape to an object whose motion you want to record. As the motion progresses, the ticker tape is pulled through the ticker timer, which draws the dots on the tape. You can then use the dots to determine how the object moved.

Goal

You are going to use a ticker timer to help make distance-time diagrams for an acceleration, a uniform motion and a deceleration.

Requirements

- ☐ ticker timer
- ☐ power supply box
- ☐ wires
- ☐ pressure switch
- ☐ three 60-centimetre lengths of ticker tape
- ☐ ruler
- ☐ graph paper

Doing the experiment and writing it up

Preparation

- You do this experiment in pairs.
- Plug the ticker timer in so that it is connected to the power supply box. Your teacher will tell you what alternating voltage the device runs on.
- Place a 60 cm strip of ticker tape in the ticker timer.

Doing the work

Measurement 1: an acceleration

- Pupil 1 gives the starting signal and switches the ticker timer on at the same time.
- Pupil 2 pulls the strip through the ticker timer at a steadily increasing speed.
  Note: the whole movement has to be recorded on the tape.
- Label the strip 'Acceleration'.
  Place an S (for 'start') by the first dot on the strip.
  Place an F (for 'finish') by the last dot on the strip.

Measurement 2: a uniform motion

- Place the second strip of ticker tape in the ticker timer.
- Pupil 1 gives the starting signal and switches the ticker timer on at the same time.
- Pupil 2 pulls the strip through the ticker timer at a steady speed.
- Label the strip 'Uniform motion'.
  Place an S next to the first dot on the strip.
  Place an F next to the last dot on the strip.

Measurement 3: a deceleration

- Place the third strip of ticker tape in the ticker timer.
- Pupil 2 starts by pulling the strip through the ticker timer at a substantial speed.
- Pupil 1 then immediately gives the starting signal and switches the ticker timer on at the same time.
- From that moment on, pupil 2 pulls the strip further through the ticker timer at a steadily decreasing speed. (Practice this a couple of times without turning the ticker timer on before actually doing the experiment.)

- Label the strip 'Deceleration'.
  Place an S next to the first dot on the strip.
  Place an F next to the last dot on the strip.

Writing up

- Use a pencil and ruler to draw a line across the tape through the first dot.
- Count four dots further and place another line. Keep doing this until you get to the end of the tape (see figure 2).
- Process the other two tapes in the same way.

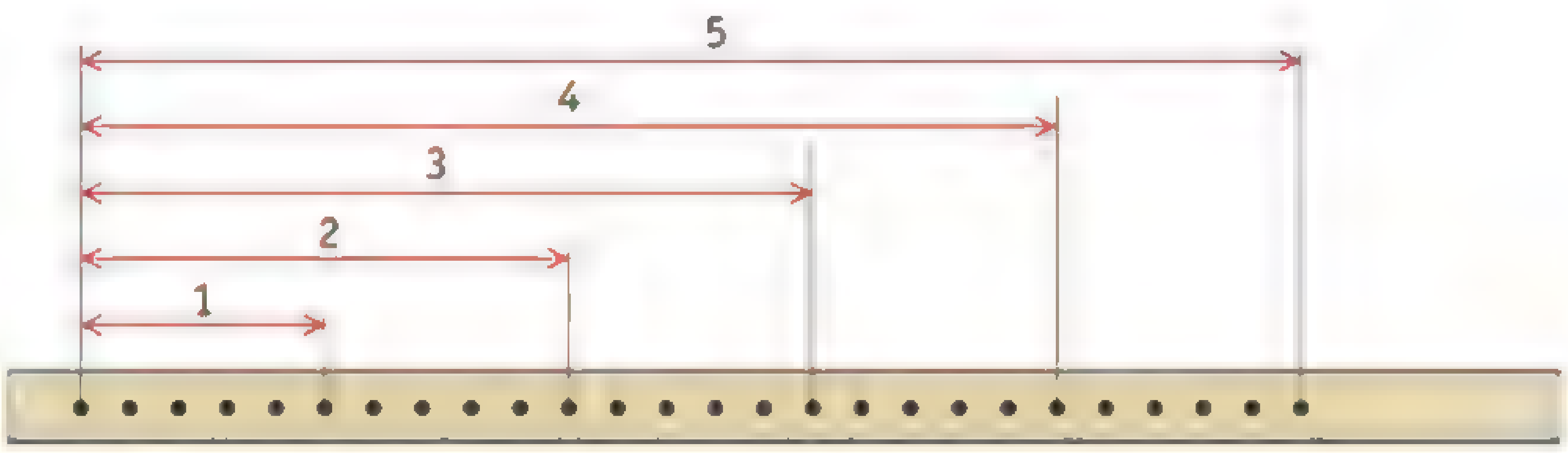


figure 2 How to place the lines on the ticker tape.

1 Measure the distances travelled as shown in figure 2.
Write down the distances at the correct places in table 2.

table 2 The measurements for Experiment 3.

		measurement 1	measurement 2	measurement 3
distance number	time (s)	distance (cm)	distance (cm)	distance (cm)
0	0	0	0	0
1				
2				
3				
4				
5				
6				
7				
8				

2 Write down the time taken to travel each distance in the second column of the table.
Some ticker timers make fifty dots a second; others make a hundred dots a second.
Your teacher will give you the details for your ticker timer.

3 Draw a distance-time diagram on graph paper:
   a of the acceleration.
   b of the uniform motion.
   c of the deceleration.

4 What does the graph look like for:

a the acceleration?

....

b the uniform motion?

....

c the deceleration?

....

5 Calculate the average speeds of the movements that were recorded on the ticker tape. Always show all your calculation steps.

....

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EXPERIMENT 4 THE BRAKING DISTANCE OF YOUR BICYCLE

45 minutes

Introduction

When you brake on your bicycle, you do not come to a halt immediately. You still travel a certain distance further during braking. This distance is known as the braking distance.

Goal

You will be investigating the braking distance for a bicycle. The question you are studying is:

How does the braking distance of your bicycle depend on the initial speed (the speed at the moment you start braking)?

Requirements

- ☐ stopwatch
- ☐ measuring tape
- ☐ bicycle with hand-operated brakes
- ☐ 2 wooden blocks
- ☐ cord
- ☐ graph paper

Doing the experiment and writing it up

Preparation

- You will be doing this experiment in pairs: pupil 1 cycles, pupil 2 records the time and measures the braking distance.
- Fix the wooden blocks to your handlebars as shown in figure 3. This will make sure you can brake using the same braking force each time.
- Mark out a distance of 10 m on the school playground or a quiet road.

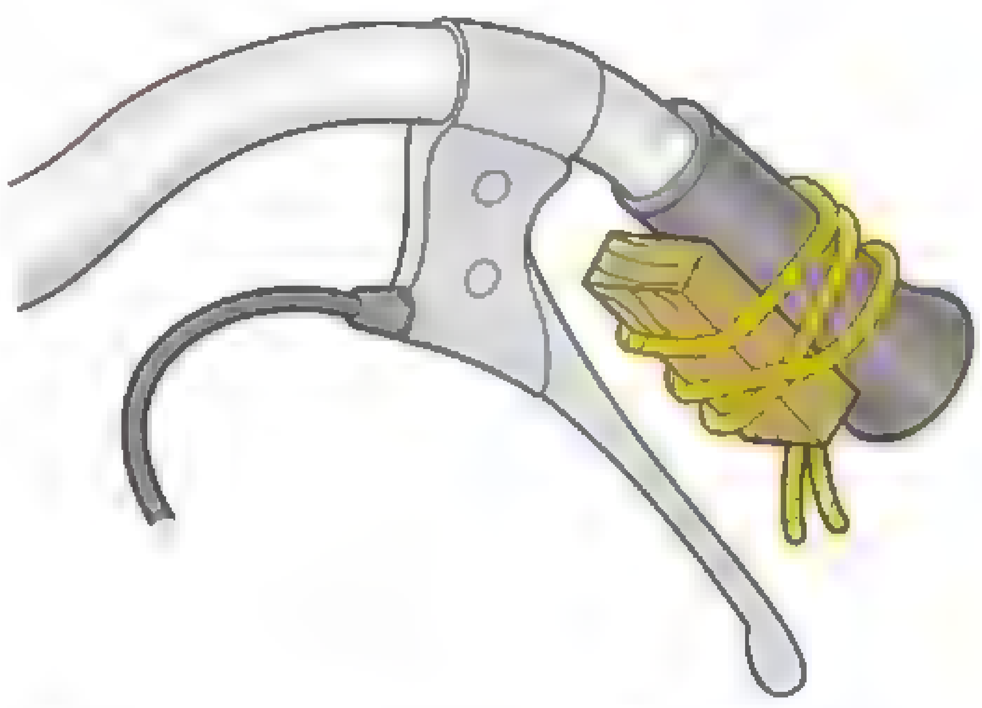


figure 3 This lets you brake with the same braking force each time.

Doing the work

- Pupil 1 cycles at a constant speed through the 10-metre section. After passing the 10-metre line, they immediately brake until coming to a halt.
- Pupil 2 measures the time that pupil 1 took to cover the 10 m. After the bicycle stops, they measure how long the braking distance was.
- Carry out the measurements stated above for five different speeds (ranging from very slow to as fast as possible).

1 Write down all the measurements in table 3: the times in the first column and the braking distances in the third column.

table 3 The measurements for Experiment 4.

10-metre time (s)	speed before braking (m/s)	braking distance (m)
-	0	0

Processing

2 Calculate the speed before braking for each measurement. Write down the speed in the second column of the table.

3 Make a graph of your observations on graph paper in which you plot the braking distance against the initial speed (with the braking distance on the vertical axis and the initial speed on the horizontal axis).

EXPERIMENT 5 REACTION TIME

15 minutes

Introduction
You have probably experienced it before: you're cycling along a busy street and all of a sudden someone comes out onto the road in front of you. It makes you jump and squeeze the brakes. But no matter how quick your reactions are, it always takes a moment before your bicycle starts braking. The time between seeing and braking is known as the reaction time.

Goal
In this experiment, you are going to determine your own reaction time.

Requirements
☐ a 30 cm ruler

Doing the experiment and writing it up
Sharing the work
You do this experiment in pairs. Pupil 1 is the test subject; pupil 2 is the tester. Halfway through the experiment, you swap roles.

Doing the work
- Pupil 2 holds the ruler at the top by the 30 cm mark. Pupil 1 holds out their thumb and forefinger at the 0 cm mark. See figure 4.
- Pupil 2 lets go of the ruler with no warning. The test subject tries to grab the ruler between thumb and forefinger as quickly as possible.

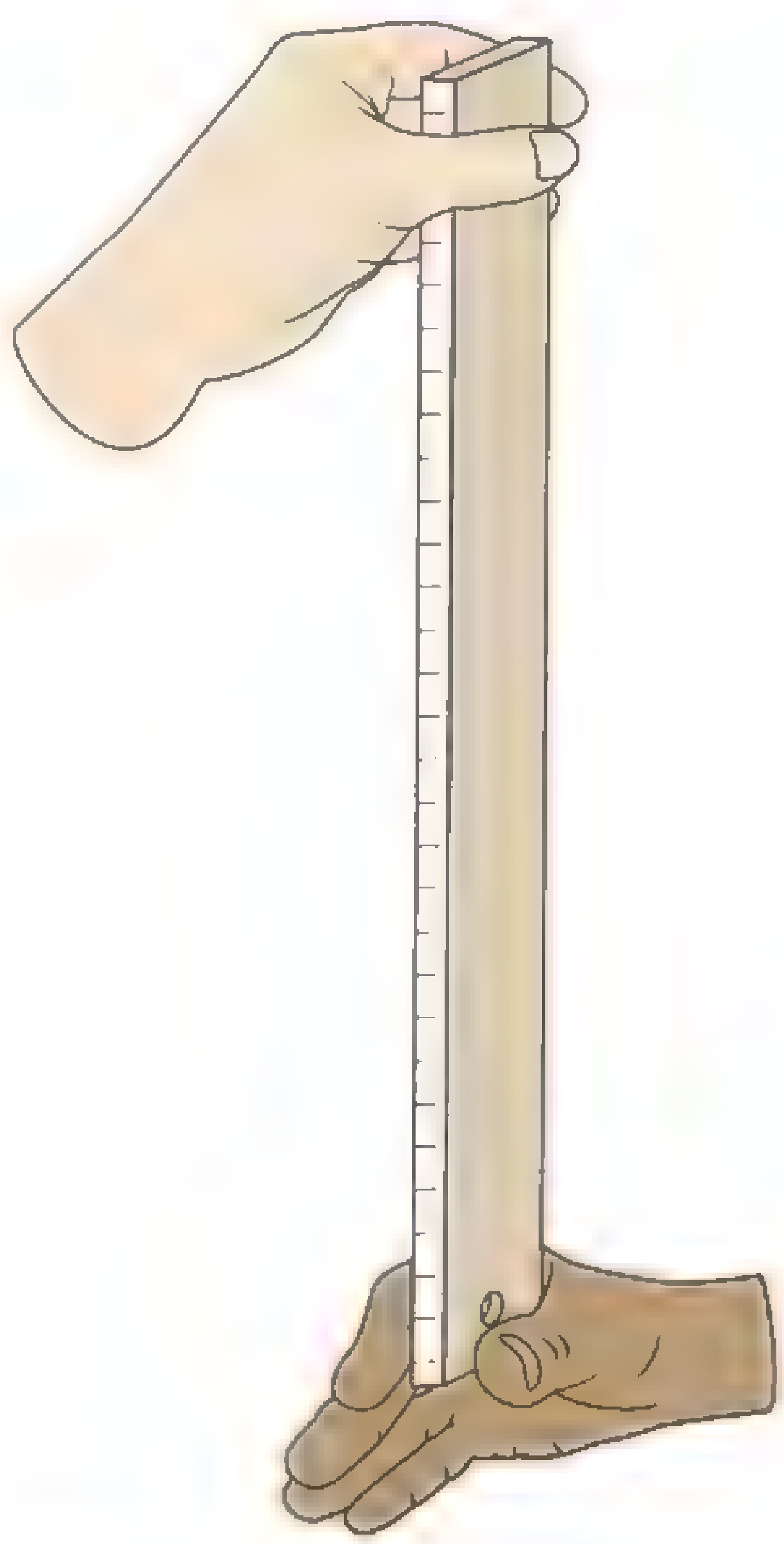


figure 4 How to do Experiment 5.

1 Write down the distance the ruler falls in table 4. This distance can be read directly off the ruler.

table 4 The measurement data from Experiment 5.

test subject	distance fallen (cm)	reaction time (s)
pupil 1		
pupil 1		
pupil 1		
pupil 2		
pupil 2		
pupil 2		

- Do this experiment a total of three times. Then swap roles. Now repeat the experiment three times, this time with pupil 2 as the test subject.

Writing up

2 See figure 5.
Read off the corresponding reaction time for each distance fallen.
Write down the reaction time in the third column of the table.

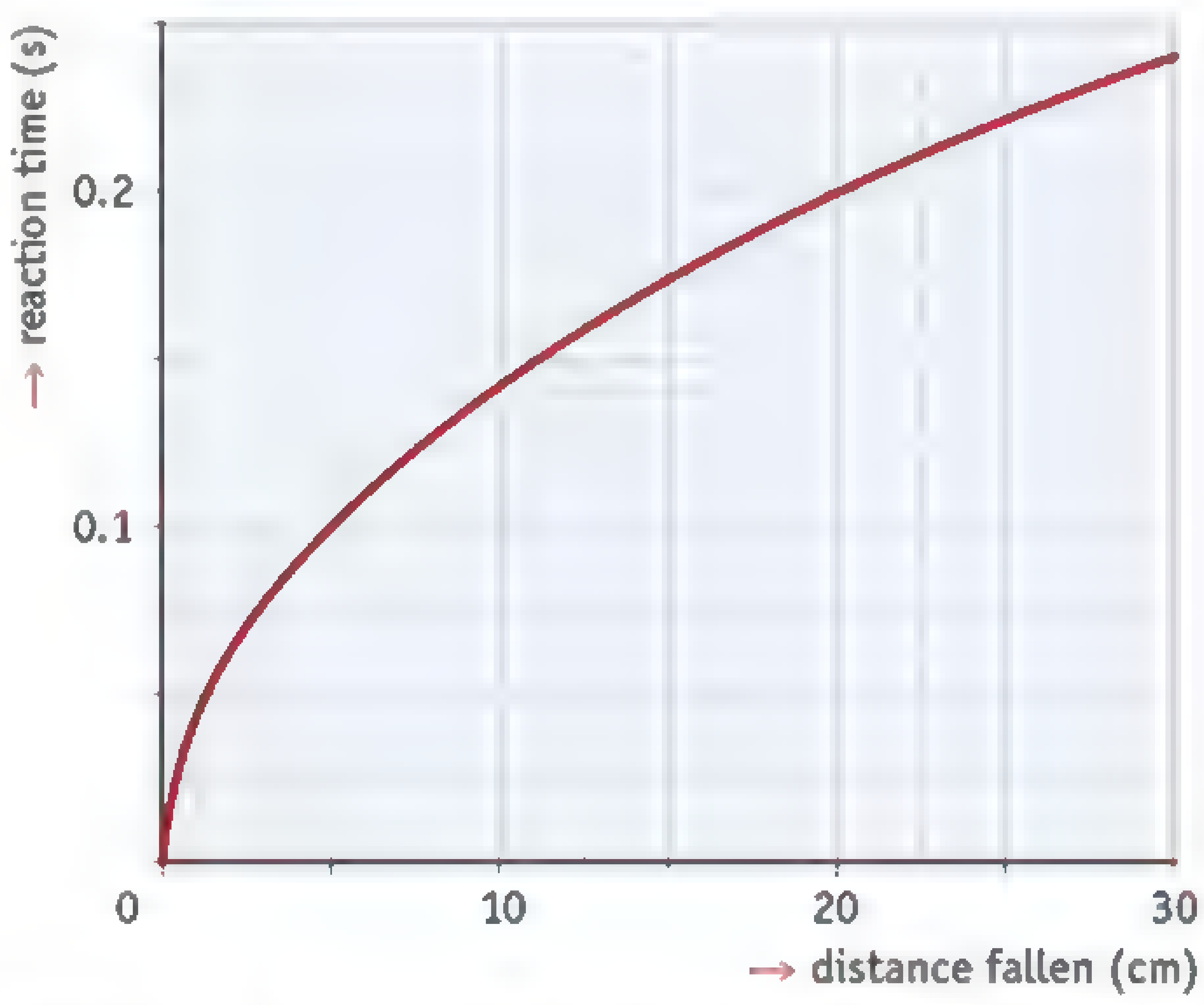


figure 5 The relationship between the distance fallen and the reaction time.

3 Work out the average reaction times below:

a for pupil 1.

....

....

....

b for pupil 2.

....

....

....

4 Having a short reaction time is often important. Write down a situation for which it is important in:

a in traffic.

....

....

b in sports.

....

....

EXPERIMENT 6 CARRYING OUT RESEARCH: BRAKING DISTANCE

45 minutes

Introduction

Suppose that a traffic safety expert states in a television programme that it is dangerous to take someone else on the back of your bike. They say that it not only makes you less stable but also makes the braking distance longer. "That may well be true," you think, "but will it really affect the braking distance all that much? It must be possible to investigate that..."

Goal

You are looking for an answer to the following research question:
What is the percentage increase in the braking distance if you have someone else on the back of your bicycle?

Requirements

For this experiment, you have to think up for yourself what equipment you will need.

Doing the experiment and writing it up

- Think about how you can give the most reliable answer to the research question. What is your test setup going to look like; what exactly are you going to measure; how will you make sure that the measurements are repeatable (and can therefore be verified)? Tip: read Experiment 4 again to get some ideas.
- Talk it through together to discuss any risks that might be involved. What can you do to make sure that this experiment can be carried out safely?

1 Make a work plan for this study.

- The work plans will be discussed with the rest of the class in the next lesson. If necessary, you can make improvements to your own work plan after that.
- Then carry out the experiment.

2 Write down all the measurements, calculations and results.

- Your teacher will tell you whether or not you have to write up a report on this experiment.

EXPERIMENT 7 DESIGNING A MODEL OF A CRUMPLE ZONE

45 minutes

Introduction
The crumple zone of a car distorts easily if a collision occurs. This makes the 'braking distance' for the occupants longer so that the impact of the collision is lessened.

Goal
You are going to design a model of a crumple zone and test it out.

Requirements
- ☐ trolley
- ☐ sloping surface
- ☐ brick
- ☐ mass (weight)
- ☐ ruler
- ☐ various materials (paper, cardboard, aluminium foil, adhesive tape, etc.)

Doing the experiment and writing it up
Preparation
- Set up the experiment shown in figure 6.
- Place the mass on the trolley (not attached to it).
- Let the trolley roll down the slope and hit the brick.
- Measure how far the mass moved (in centimetres).
- Reduce the angle of the slope if the mass shifted more than 8 cm. Raise the angle of the slope if the mass shifted less than 6 cm.
- Repeat the experiment until the shift is somewhere between 6 and 8 cm.

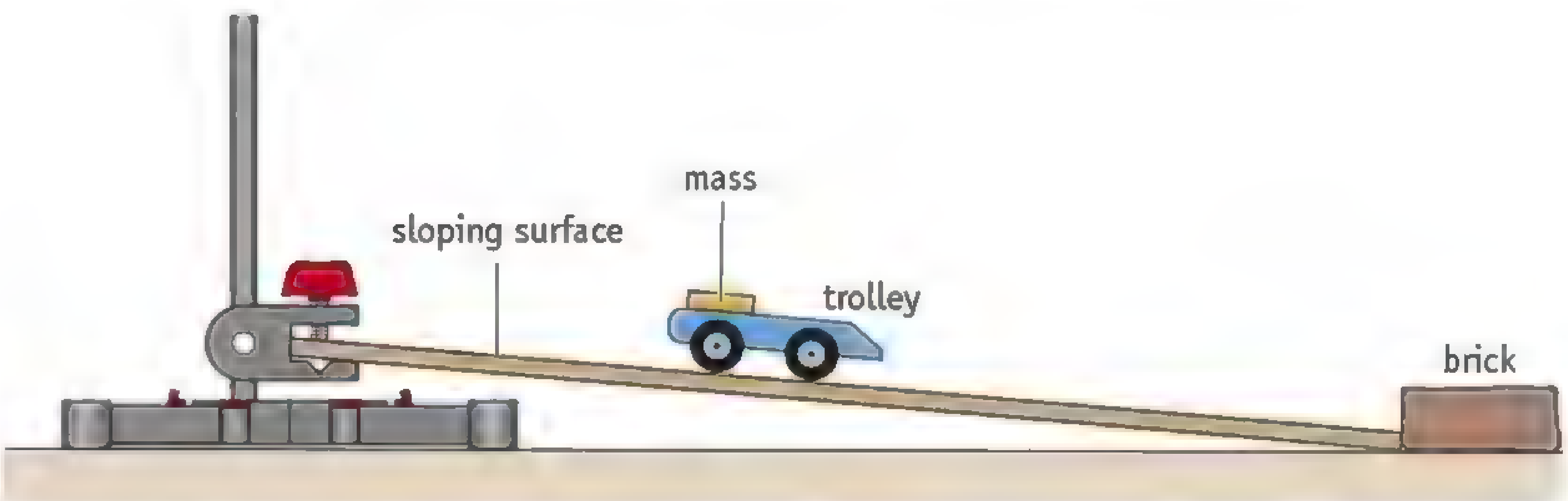


figure 6 The setup for Experiment 7.

Doing the work
- Think up how you can make a crumple zone on the front of the trolley, using the materials that you have available.
- Construct the crumple zone and test it. Your model must meet the following design requirements:

Design requirements

- The crumple zone must at least halve the amount by which the mass shifts.
- The crumple zone must have the least possible mass (because the car must definitely not be any heavier than necessary).

- Improve your design until the crumple zone meets the design requirements.
- If you have enough time, you can also try out other designs. Try to keep the amount of material as low as possible: the less the crumple zone weighs, the better.

Presentation

- Show the class what your crumple zone looks like.
- Explain why you chose these materials and the particular shape, and how you tested and improved the design. When you have tested the various designs, write down which was best and why.

Aerial acrobats in slow motion

A group of geese are landing. Just before the birds come down onto the water, one goose does an astonishing aerial acrobatic stunt. It flies upside down, with its belly up and its feet pointing to the sky. Only the head is still looking forward as normal because its neck has twisted through 180 degrees. This seems to be a unique trick, but that is not remotely the case: a couple of other geese immediately follow suit.

Slow motion

The aerobatics of the geese have been recorded in slow motion thanks to a unique project called *De Vliegkunstenaars* (Flight Artists) at Wageningen University. This project loaned high-speed cameras to volunteers: nature lovers, amateur photographers, artists and others who were interested. Their assignment was to make recordings of aerial acrobatics in nature.
The project participants filmed a very wide range of subjects – recordings were made of a fly doing a somersault, an aerial combat between sparrows, and a honey bee colliding with a bumblebee. Researchers are using the pictures to study how birds and insects fly. Normally, the wings move much too fast for this to be seen properly.

A normal video recording such as a *YouTube* clip consists of 24 to 30 pictures (frames) a second. If you watch a recording like that at the normal speed, you do not see the individual frames. Instead, you see a fluid movement. That changes if you play the recording back

ten times more slowly. Then you do see a sequence of individual pictures that do not give the appearance of a fluid motion.

A high-speed camera is designed to record movements that are too fast to follow with the naked eye (figure 1). To do this, the camera has to record far more images than a normal video camera. A recording may for example be at 300 frames a second. If you then play that recording back ten times more slowly, one second seems to last ten seconds. Because it is being played back at 300 ÷ 10 = 30 frames a second, the motion still appears fluid.

figure 1 A high-speed camera.

This kind of representation – slowed down but still fluid – is called *slow motion*. Slow motion is not only useful in science for recording motions so that they can be investigated. The same technique is often used in films, for example to make a dramatic scene even more impressive or to show every detail of an action scene.

Slow-motion recordings of birds and insects are hugely valuable in the quest for optimum wing designs.

Flight Artists

More than two thousand clips were made by 460 volunteers for the *Flight Artists* project. These clips are freely available on the Internet and may be used for class presentations, scientific research and anything in between! It means that you can now calmly enjoy the wonderful flying motions of the everyday flying artistes around us, from butterflies to sparrows and from bats to sycamore seeds.

The recordings have yielded all sorts of new information. It has been known for some time, for example, that geese occasionally fly on their backs, but the researchers knew very little more than that because the geese perform the manoeuvre so quickly that it is almost impossible to follow with the naked eye. One of the volunteers managed to film this behaviour for the first time with a high-speed camera. Thanks to him, the entire flying movement can now be seen in slow motion.

The Wageningen researchers are primarily interested in how the wings of birds and insects actually move while flying. Slow motion recordings are an indispensable tool for them. David Lentink, who set up the project, says, "We have recordings of a wasp, for example. It has two pairs of wings, just like other insects, but when it flaps them – warming up before taking off – the wings catch and interlock, effectively making them just a single wing pair. I had never seen that before."

The wings of birds and insects function very differently from the rigid wings of an aircraft. They are lightweight, flexible structures that can make all sorts of complex movements. The wings do not merely move up and down as the animal flies, but they also twist and are distorted in various ways during the motion as well. All these movements are very effective: many birds and insects are real aerial acrobats – fast and highly manoeuvrable.

DID YOU KNOW...

One of the most famous slow-motion scenes comes from the film *The Matrix* (1999). In this scene, the camera seems to be moving around the main character, Neo. This scene was not made using a single high-speed camera. Instead, it used 120 different cameras that took pictures in turn, each one shortly after the previous one.

Flying like a dragonfly

Knowledge such as that accumulated by the Wageningen researchers is interesting for other people besides nature lovers. That knowledge is currently also being applied in designs for ultra-small aircraft. The very smallest of these imitate the way birds and insects

figure 2 A dragonfly.

figure 3 The *DelFly Micro*.

fly. They do not have large, fixed wings like a normal aircraft but instead use small moving, flexible wings.
Slow-motion recordings of birds and insects are hugely valuable in the quest for optimum wing designs.

And that search is already starting to bear fruit, such as the DelFly project at Delft Technical University. The project, which started in 2005, has yielded various miniature aircraft such as the *DelFly Micro*, at 10 cm in length and with a mass of 3 g, that flies like a dragonfly (figures 2 and 3). In 2018, the *DelFly Nimble* was presented. In contrast to its predecessors, it is not controlled using controls on the tail or behind the wings (as aeroplanes are). Instead, it is controlled solely by adjusting the movement of its flapping wings, exactly the same way insects do. The *DelFly Nimble* has no tail so it is less vulnerable and much more agile. The design team at Delft Technical University hope to be able to help fire brigades locate the sources of fires in burning buildings or locate survivors in collapsed buildings. This tiny robot could also be used by the police, for example to reconnoitre a house before carrying out a raid.

Increasing numbers of robots are now being developed that fly like insects or birds. At Leuven University in Belgium, a student called Frederik Leys developed the *Kulibrie*, a flying robot weighing 4 g that was inspired by the way a hummingbird (or kolibrie in Dutch) flies. At Harvard University in the United States, the *Robobee* has been developed. This is a robot of less than 0.1 g that can fly, dive and jump out of the water. The idea is that these *Robobees* will behave like a colony – the same hive behaviour as real bees.

So clips that have been made using high-speed cameras do more than just provide interesting visual material: they can also lead to surprising insights. In the future, ultra-small aircraft may be able to carry out all sorts of tasks that we are currently only able to dream of – all based on the aerobatics of birds and insects.

A WATER BALLOON BURSTING

High-speed cameras are also used for all sorts of other studies. Impressive clips have been made, for example, of balloons of water bursting. To the naked eye, it looks as if the balloon bursts in a single moment and the water cascades downwards. However, film clips taken at very high speeds show that the balloon first rips open and the water hangs there in the shape of the balloon for a moment (figure 4).

figure 4 A water balloon bursting.

EXERCISES

1. A video has been recorded at 450 frames per second and is played back at 30 frames per second.
   - **a** How much slower does the movement recorded on the video clip now seem?
   - **b** There are already professional cameras available that can film at a million frames per second.
     How much slower would the motion recorded with that type of camera appear when played back at 30 frames per second?

2. The cameras used for the *Flight Artists* project make recordings at 600 frames per second. On a clip made with one of these cameras, a bumblebee takes 12 frames to move 10 cm. Calculate the average speed of the bumblebee. Give your answer in m/s and km/h.

3. The *DelFly Nimble* can stay airborne for five minutes.
   Explain what the difficulties are in making such a small aircraft fly for longer.

Course material overview

5.1 RECORDING MOVEMENTS

REMEMBER

- You can record a movement using a stroboscopic photo.
- The data for a distance-time table can be obtained from a video recording or a stroboscopic photograph. You do then need to know:
  - the time intervals between the individual 'snapshots';
  - the actual distances represented in the photographs.
- An (x,t) diagram is a shorter name for a distance-time diagram. You can read off the position of the object at any time from it.
- The difference between two measured values is called the 'distance travelled'.

CONCEPTS

distance covered
Difference in distance between two measured values. The symbol for distance is *s*.

distance-time diagram
Coordinate system in which the position or displacement (x) is plotted against the time (t).

distance-time table
Table in which the position or displacement (x) of an object is given for a series of points in time (t).

scale
Ratio between the actual size of an object and the size at which it is shown in an image.

stroboscopic photo
Photograph that is taken in a darkened room, using a stroboscope as the only light source.

video recording
Series of images made at brief intervals.

(x,t) diagram
Another term for a distance-time diagram.

5.2 AVERAGE SPEED

REMEMBER

- You can calculate the average speed by dividing the distance covered by the time taken: $v_{avg} = \frac{s}{t}$.
- You can convert a speed in m/s into km/h by multiplying by 3.6. A speed in km/h can be converted into m/s by dividing by 3.6.
- You can calculate the distance travelled by multiplying the average speed by the time taken: $s = v_{avg} \cdot t$.
- You can calculate the time taken by dividing the distance covered by the average speed: $t = \frac{s}{v_{avg}}$.
- A (v,t) diagram is a shorter name for a speed-time diagram. It lets you read what the speed of the object is at any given time.
- If the object's speed is increasing or decreasing evenly, you can calculate the average speed using $v_{avg} = \frac{v_{init} + v_{final}}{2}$.

CONCEPTS

average speed
The distance travelled divided by the time taken.

speed-time diagram
Coordinate system in which the speed (v) is plotted against the time (t).

(v,t) diagram
Another term for a speed-time diagram.

5.3 ACCELERATION – UNIFORM MOTION – DECELERATION

REMEMBER

- When you are cycling, your speed is not the same at all times. There are three types of motion:
  - a motion in which the speed keeps getting greater is called an acceleration;
  - a motion during which the speed does not change is called a uniform motion;
  - a motion in which the speed keeps getting less is called a deceleration.
- You can tell an acceleration in an (x,t) diagram from a curve that keeps getting steeper. In a (v,t) diagram, you can tell this from an upward line.
- You can tell a uniform motion in an (x,t) diagram from a graph that is a straight line (upward or downward). In a (v,t) diagram, you can tell this from a horizontal line.
- You can tell a deceleration in an (x,t) diagram from a curve that keeps rising more slowly. In a (v,t) diagram, you can tell this from a downward line.
- If the graphs of two vehicles are shown in an (x,t) diagram, the point where the graphs cross is the point where the vehicles pass.

CONCEPTS

acceleration
Movement in which the speed increases.

deceleration
Movement in which the speed decreases.

uniform motion
Movement in which the speed remains constant.

5.4 BRAKING AND COLLISIONS

REMEMBER

- The braking distance of a car depends on:
  - the initial speed;
  - the mass;
  - the braking force.
- The braking force a vehicle can apply depends on the condition of the road, brakes and tyres.
- For the braking distance: if the speed is n times greater, the braking distance becomes n^2 times longer.
- The reaction time depends on the alertness of the driver (fatigue) and whether they have been using alcohol/drugs.
- During the reaction time, the vehicle's motion stays effectively uniform (in other words, at the initial speed). The distance that the vehicle covers during the reaction time is called the reaction distance.
- You can calculate the overall stopping distance by adding the reaction distance and braking distance together: stopping distance = reaction distance + braking distance.

CONCEPTS

braking distance
Distance covered by a vehicle while braking.

reaction distance
Distance covered by a vehicle during the reaction time.

reaction time
Time between seeing the hazard and applying the brakes.

stopping distance
Overall distance that a car needs to come to a stop.

Go to the *Flash cards* and the *Diagnostic test*.

6 Light

A WORLD FULL OF LIGHT

Light is not only needed to be able to see things. It also provides colour and atmosphere. Lighting designers and architects use light to create precisely the effects that they want, whether that is a spectacular lighting show or an attractively lit town centre.

1 Light and colour

LEARNING OBJECTIVES

6.1.1 You can give an example of a natural light source and an artificial light source.
6.1.2 You can describe how you see objects in your surroundings.
6.1.3 You can explain what a spectrum is and how you can make one visible.
6.1.4 You can explain how you see an object of a specific colour in various colours of lighting.
EXTRA 6.1.5 You can explain what subtractive and additive colour mixing is.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES				
	6.1.1	6.1.2	6.1.3	6.1.4	6.1.5
Remembering	3ab	2abc	1ad, 8a	1bce	11ab
Understanding			8b	6abcdef, 9a, 10a	
Using	4		8cd	5ab, 7, 9	12ab, 13b
Analysing				10bc	13ac

When it is misty, you can sometimes see the sun appear through the mist as a clear white disc. You can get a good look at the sun then because the sun is not as blindingly bright as usual. That is no longer possible when the mist has cleared and you can see the world around you again in full sunlight.

LIGHT FROM THE SUN

The sun is the most important natural light source on the Earth (figure 1). Life on Earth would be inconceivable without sunlight.

figure 1 The sun breaking through the mist.

The sun's white light comprises all the colours of the rainbow. This can be demonstrated by letting sunlight pass at just the right angle through a triangular piece of glass called a prism (figure 2). A whole series of colours can then be seen on a screen placed behind the prism: red, orange, yellow, green, blue and violet. A sequence of colours like this is called a spectrum.

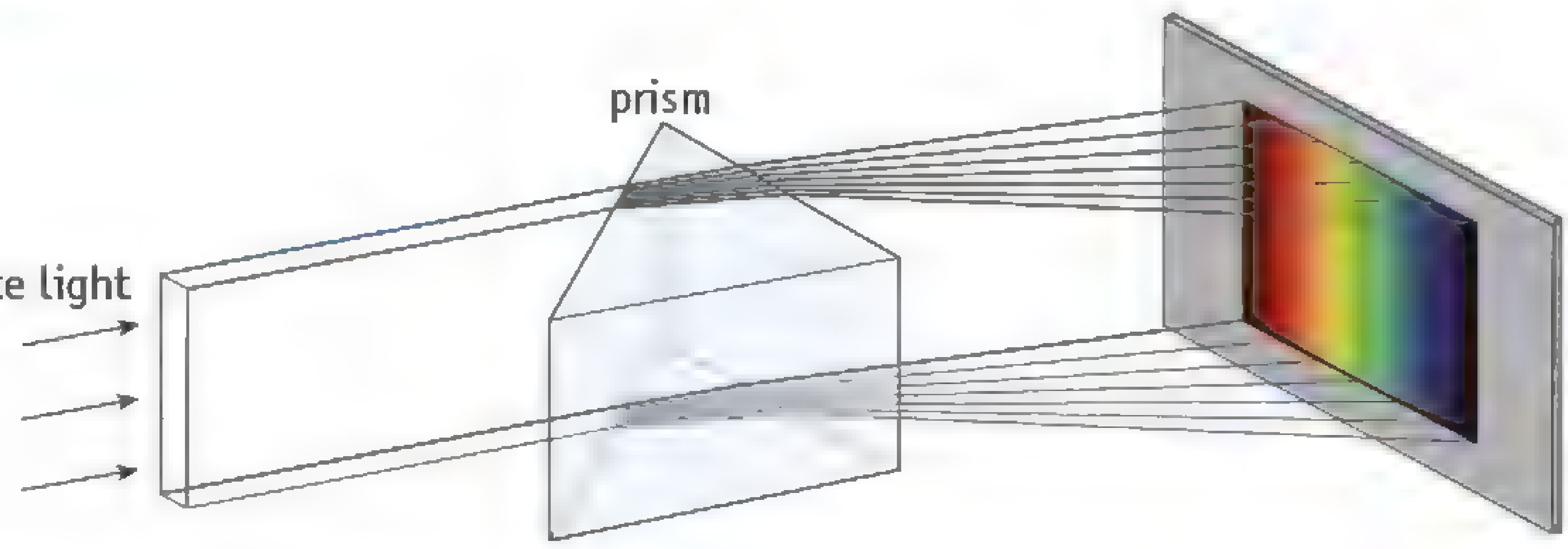


figure 2 Making a spectrum with a prism.

You can use a second prism to merge the various colours of light in the spectrum back together. You then get the original white of the sunlight back again. Experiments like these show you that sunlight is a mixture of different **spectral colours** (the pure colours in the spectrum).

SEEING YOUR SURROUNDINGS

Most of the things you can see around you do not emit light themselves. You can only see them when they are illuminated. The light that falls on the object is then **reflected diffusely** (in all directions). You see the object when a proportion of this reflected light is reflected into your eyes.

During the daytime, the objects around you are lit by the sun. You then see the world 'in colour' (figure 3). The various colours arise because many objects only reflect part of the sunlight falling on them. For example, something that is red reflects primarily the spectral colour red, and a blue object reflects principally the spectral colour blue. The remaining light is absorbed by the object and converted into heat.

figure 3 Colours arise because the light is reflected differently.

White objects reflect almost all the sunlight falling on them. All the spectral colours are reflected. The reflected light therefore has the same composition as the original sunlight. Black objects, however, reflect very little light. Almost all the sunlight is **absorbed**, irrespective of the colour of the light.

THE SPECTRUM OF LAMP LIGHT

EXP

Candles, LED bulbs and fluorescent tubes are **artificial light sources**: they have been manufactured by humans. You can use a **pocket spectroscope** to study the light they emit. If you look at a light through a spectroscope like this, you see a spectrum of the bulb's light (figure 4). This lets you determine the spectral colours that make up that light.

figure 4 How to use a pocket spectroscope.

A halogen bulb and a fluorescent tube both emit white light. But if you look at the spectra of these lights, you will see clear differences. The spectrum of a halogen bulb is even, much like that of sunlight (figure 5a). The spectrum of the light from a fluorescent tube is dominated by certain spectral colours (the bright lines), whereas other spectral colours are very weak (figure 5b). Coloured objects can appear different in this kind of light, compared to in sunlight. Some light sources only emit a single colour of light (figure 5c).

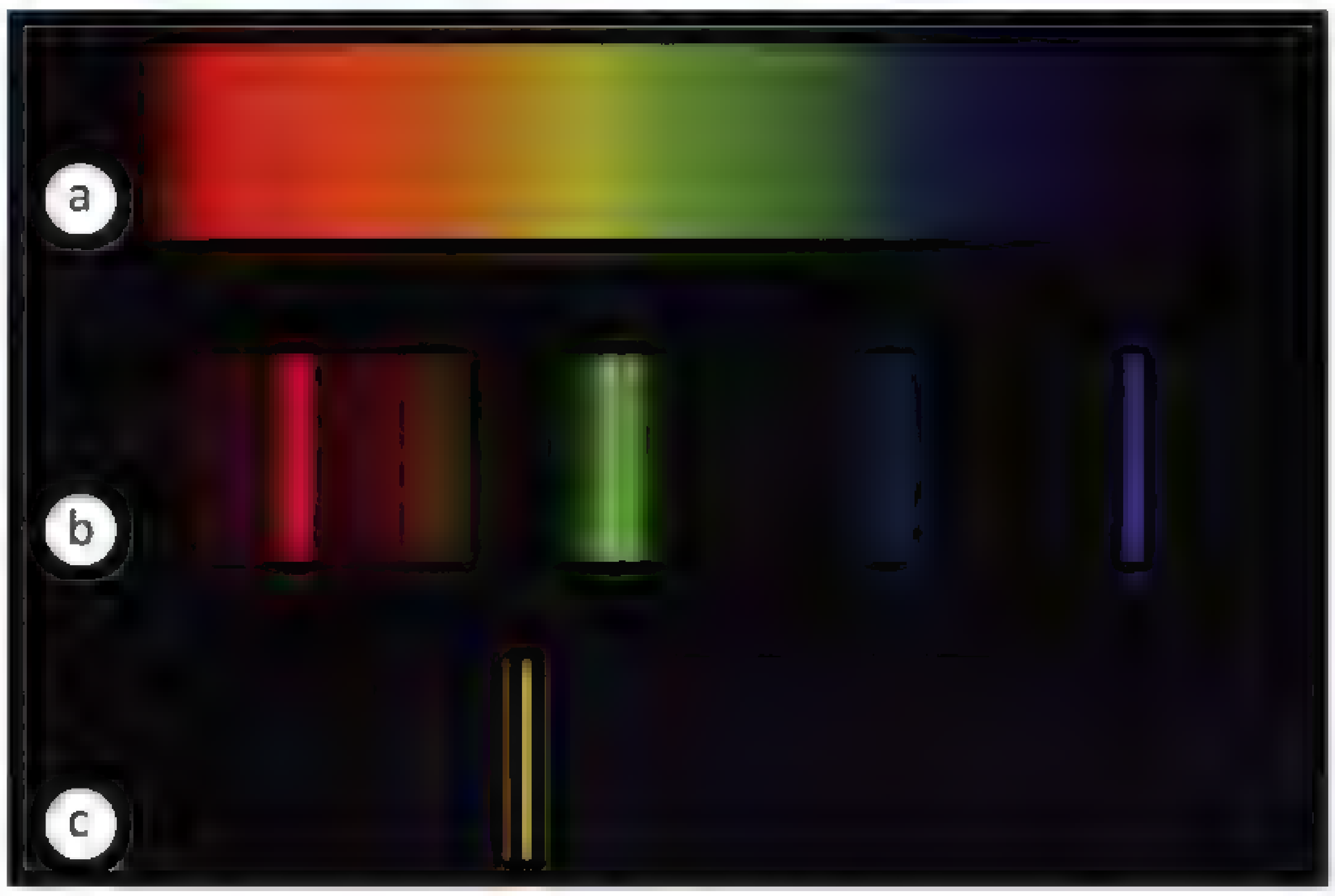


figure 5 The spectra of a halogen bulb, a fluorescent tube and a sodium lamp.

When choosing light sources, people do not only look at the amount of light: the colour of the light is also important. Light that contains a lot of red, orange and yellow gives a warm impression. Light that has a lot of green and blue is neutral, or can even seem cold. Warm light is used a great deal in rooms that are intended to be cosy and friendly. For work areas, clear white, neutral light is generally used.

SEEING COLOURS

There are also light sources that just emit a single colour of light. Sodium lamps give pure yellow-coloured light, for example. Their spectrum comprises just two narrow lines in the yellow/orange range (figure 5c). Sometimes you can also see a red line and a green one, which come from neon gas.

The world looks very different under sodium lighting from what you normally see (figure 6). A purple jumper can for example look dark grey or black. This is because the jumper almost completely absorbs the yellow/orange light of the sodium lamp. A white jumper and a yellow jumper will both look yellow under a sodium lamp. The yellow light of the sodium lamp is reflected equally strongly by both jumpers.

figure 6 This street is lit by sodium lamps.

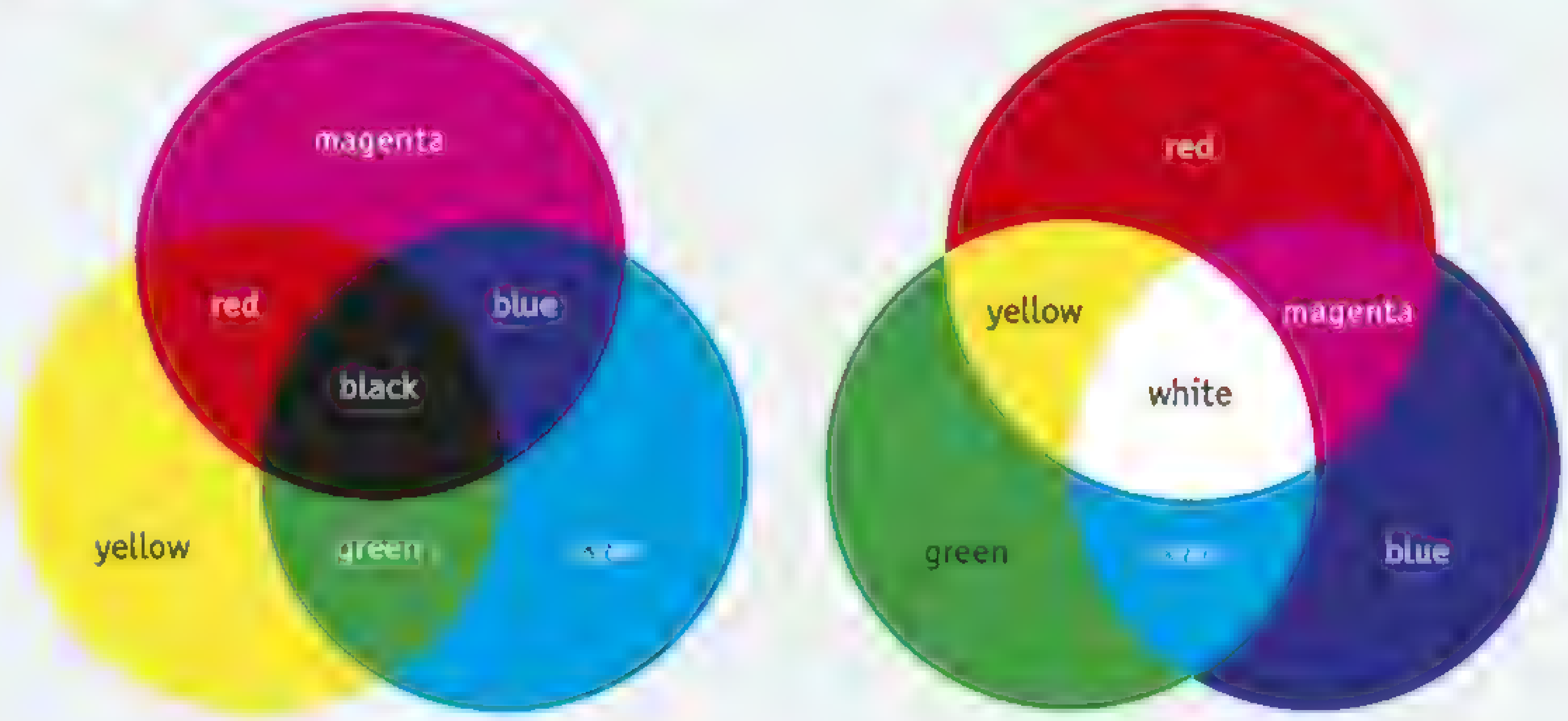
Practice the concepts using the *Flash cards*.

EXTRA SUBTRACTIVE AND ADDITIVE COLOUR MIXING

In colour printers, various colours of ink are mixed together to create other colours. The inks contain pigments that absorb some colours but let others pass through. The ink acts as a filter. When white light lands on paper with yellow ink on, blue light is absorbed. We see what is reflected as yellow light. Mixing inks of different colours lets you make other colours. This is subtractive colour mixing (figure 7a). If you print a photo out on paper, the printer uses very tiny droplets of ink in the basic colours cyan, magenta and yellow. This lets the printer produce all possible colours.

It works differently for coloured light. If you mix red, green and blue light, you get white light (figure 7b). This is additive colour mixing. You are adding colours here instead of absorbing them. Your smartphone uses this cleverly to allow all possible colours to be shown on the screen.

figure 7 Subtractive and additive colours.



ⓐ ⓑ

COURSE MATERIAL

1 Answer the following questions.

a Which six (spectral) colours make up the spectrum of sunlight?

b What does a red object do to the sunlight falling on it?

c What does a black object do to the sunlight falling on it?

d What instrument can you use to examine the light emitted by a lamp?

e What does a white object look like under sodium lighting?

2 Complete.

a Objects that do not emit light themselves can only be seen if they are ....

b The light that falls on such an object is reflected .... (i.e. in all directions).

c You see the object when part of the reflected light reaches your ....

3 Not all light sources give the same light.

a Which natural light source gives clear white light?

b Which artificial light source gives pure yellow/orange light?

IN PRACTICE

4 A photographer who is taking photos of clothing for a website uses daylight lamps that give the same colour of light as the sun during the daytime.
Write down two reasons why the photographer uses these lamps and not simply sunlight.

5 Table 1 shows four differently coloured T-shirts.
Complete the table and write down:
a a plus sign (+) if the T-shirt largely reflects the light.
b a minus sign (–) if the T-shirt largely absorbs the light.

table 1 Reflecting or absorbing?

clothing item	pure red light	pure green light	pure blue light
white T-shirt			
green T-shirt			
red T-shirt			
black T-shirt			

6 Compare the two photographs of Marinda in figure 8.
a Which photo was taken in clear white daylight?
the photo on the left / the photo on the right
b What lighting was used for the other photo?
c In which photo do the colours appear as they really are?
the photo on the left / the photo on the right
d What is the actual colour of the coffee cup?
e What colour does the coffee cup appear in the other photo?
f What makes the colour appear different?

figure 8 Two photographs of Marinda.

7 Jasmine is out shopping in a shop that uses coloured fluorescent lighting. She has found a jumper that she thinks looks particularly good. But before she buys it, she takes it to the door first so that she can see it in daylight.
What is the point of doing that? Explain your answer.

8

The packaging of light bulbs often states their colour temperature. That tells you what kind of colour light the bulb produces. The colour temperature is measured in kelvin (K). Light with a low colour temperature (for example 3000K) has a warmer colour. Light with a high colour temperature (for example 6500K) has a cooler colour.

a What colour temperature is stated on the packaging in figure 9?
b What kind of impression will the light from this bulb make: warm, neutral or cool?
c Is the light from this bulb suitable for creating a warm and cosy atmosphere? Explain.
d The back of the packaging states the CRI value. This 'colour rendering index' says how natural the colours of an object lit with this light source are. A high percentage means better colour representation (table 2). This bulb has a CRI value of >80.
Is the light from this bulb suitable for judging colours? Explain.

figure 9 Part of the packaging of an LED lamp.

table 2 Colour rendering.

CRI value	category	description
100-90	excellent	natural colour rendering
90-80	good	relatively natural colour rendering
80-60	moderate	the colours seen can differ from the real colours
<60	poor	the colours perceived are different from the real colours; for use where colour representation is not important (outdoor lighting, for example)

From: lumeco.nl

9

Dennis plays football for Southampton, in a white shirt with red stripes. If he walks under a sodium lamp, he will appear to turn into a player from a different football club.
Which club is it?

- ○ A Crystal Palace (red and blue stripes)
- ○ B Brighton and Hove Albion (blue and white stripes)
- ○ C Newcastle United (black and white stripes)
- ○ D Watford (black and yellow stripes)

★ 10

Car parks often used to be lit with sodium lighting. This type of light is being used less and less often now because it makes colours very difficult to recognize.
Explain why:

a colours cannot be recognized properly under this type of lighting.
b this gives problems in large car parks with large numbers of vehicles.
c people are more likely to feel unsafe with this type of lighting.

Test what you know with *Test yourself*.

EXTRA SUBTRACTIVE AND ADDITIVE COLOUR MIXING

11 Answer the following questions.

- a What three colours of light can be mixed to make white light?
- b What colour would you get if you print cyan and magenta ink close together or on top of each other?

12 By altering the proportions of colours, you can make different colours than the ones shown in figure 7.

- a How could you make a colour that is between cyan and blue using light?
- b How could you mix orange with inks?

★ 13 Most printers use black ink as well as the three basic colours. The black ink is then used for black text and black-and-white photographs.

- a Why is black ink used for the text rather than the three basic colours on top of one another?
- b How can the printer make light grey on white paper, using only black ink?
- c When you print a picture out on a printer, you also have to say what kind of paper it is. Every type of paper absorbs the ink differently. Mat paper absorbs ink much better than gloss paper. On glossy paper, more of the ink remains on top of the paper, so the colours are more clearly visible. Figure 10 shows ink droplets on paper.
  Explain why the colours are more clearly visible on glossy paper.

figure 10 Ink droplets on paper.

2 Direct, indirect and diffuse

LEARNING OBJECTIVES

6.2.1 You can draw rays.
6.2.2 You can explain what the distance between the rays that are drawn means.
6.2.3 You can explain how you can find the size of the umbra.
6.2.4 You can determine where the umbra and penumbra are.
6.2.5 You can explain the difference between direct, indirect and diffuse light.
6.2.6 You can explain what reflection and scattering are.
EXTRA 6.2.7 You can explain what causes the blue colour of the sky and the red colour of the setting sun.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES						
	6.2.1	6.2.2	6.2.3	6.2.4	6.2.5	6.2.6	6.2.7
Remembering	1ab	1cd		2abcd	3abc, 7bd	10a	11abc
Understanding		6e			7ac, 8abc, 9b	9ab, 10b	12a
Using		6abcd	4, 5b			8d, 9c, 10c	
Analysing			5a			10de	12b

On the beach on a hot summer's day, light is coming from all directions: directly from the sun, reflected by the sand and the sea, and scattered by the air above your head. Even in the shade, you need sunglasses so that you do not have to squint as you look around.

LIGHT AND SHADE

The light that is radiated by a light source disperses in all directions. You can indicate that by drawing in rays. The rays are straight because light moves in straight lines (figure 1). An arrowhead in the ray shows the direction it is travelling in. The greater the distance from the light source, the weaker the light. You can see that because the rays become more and more separated.

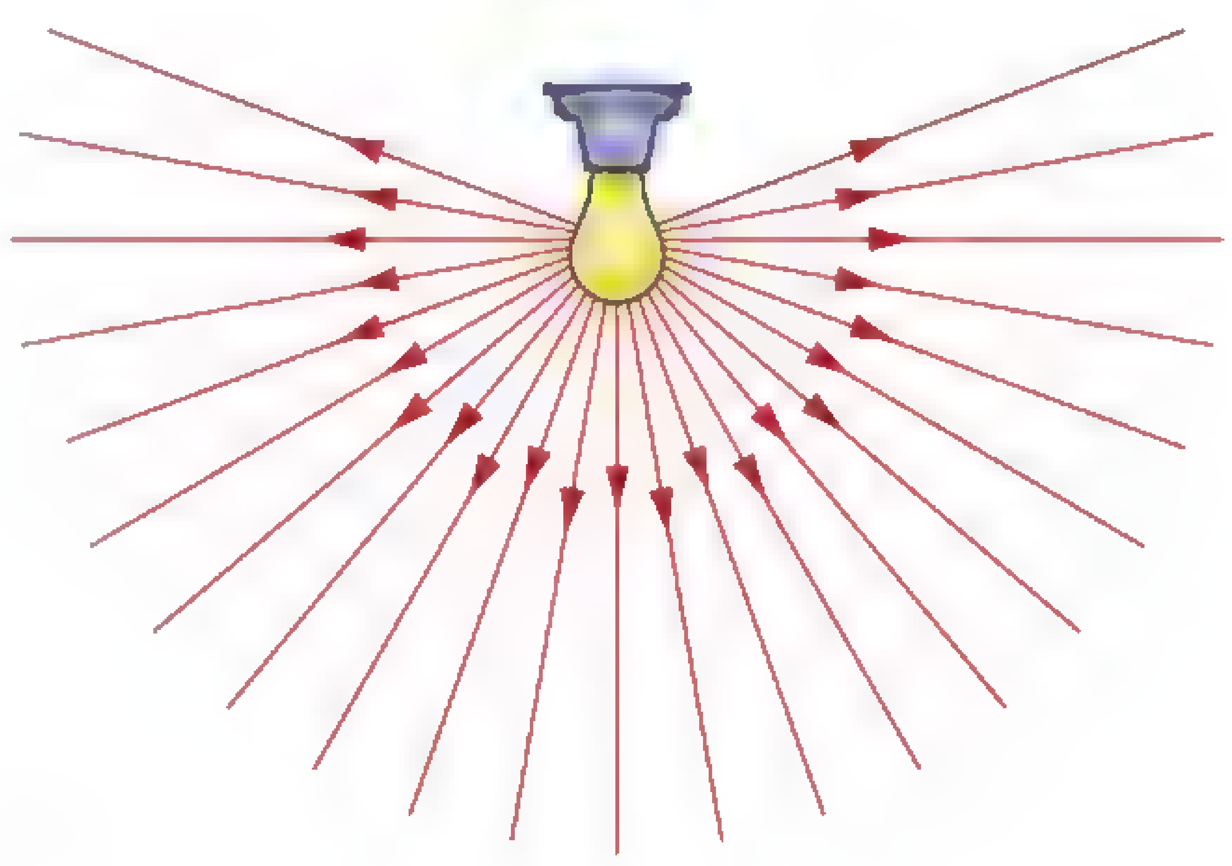


figure 1 The rays show how the light moves.

If an object blocks the light from the light source, it creates a **shadow.** There is then a region that the light cannot get to directly. Because light moves in straight lines, it is easy to determine the size of the shadow area (figure 2):

1. Draw in the two rays that are not quite blocked by the object (the **edge rays**).
2. Hatch in the area behind the object that is in between the two edge rays. This is the area that the light cannot reach directly: the shadow.

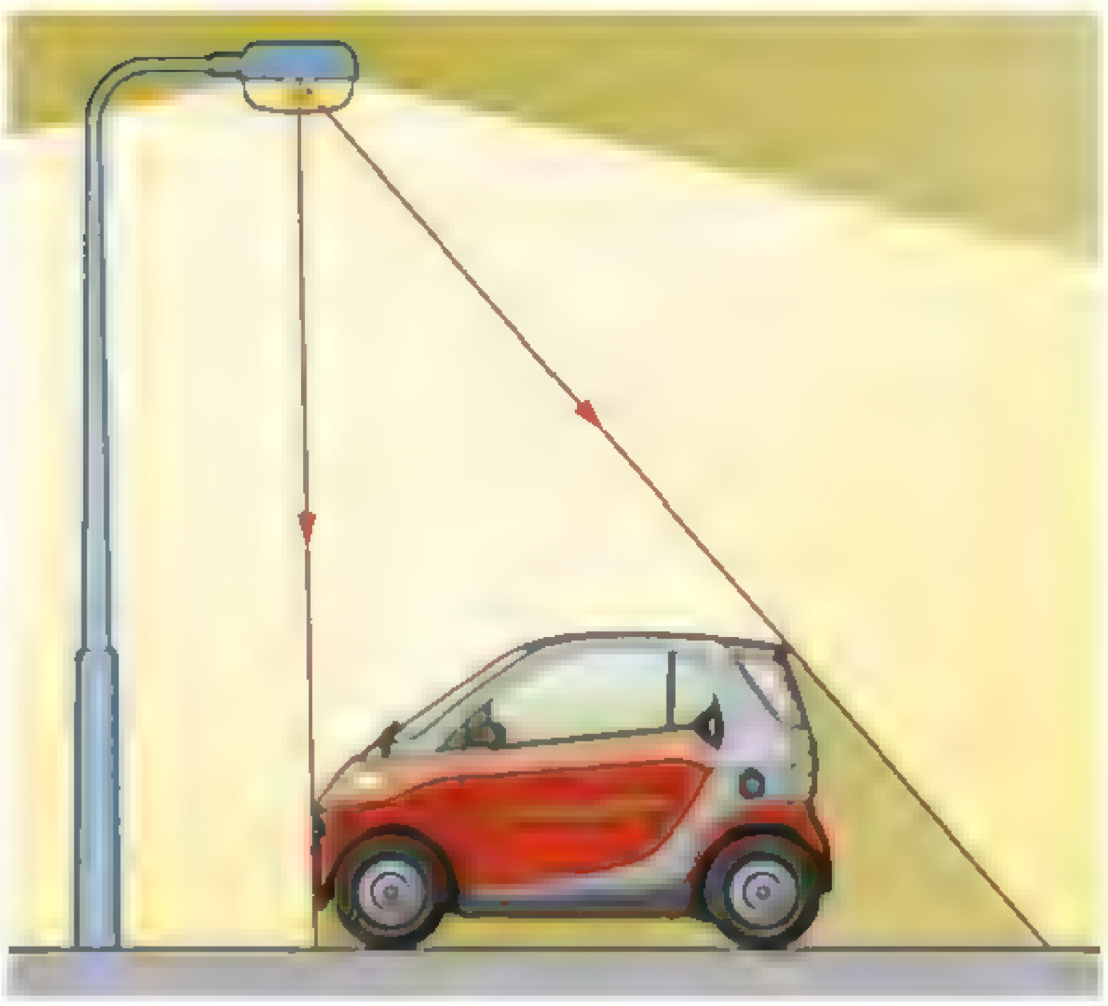


figure 2 This is how to draw in the shadow of an object.

DIRECT LIGHT

EXP. 1

Most household jobs are done indoors on a table, desk or worktop. The working surface has to be well illuminated. This should preferably be done with lamps that provide **direct light.** That is to say, the light goes directly from the light source to the working surface, as for the reading lamp in figure 3.

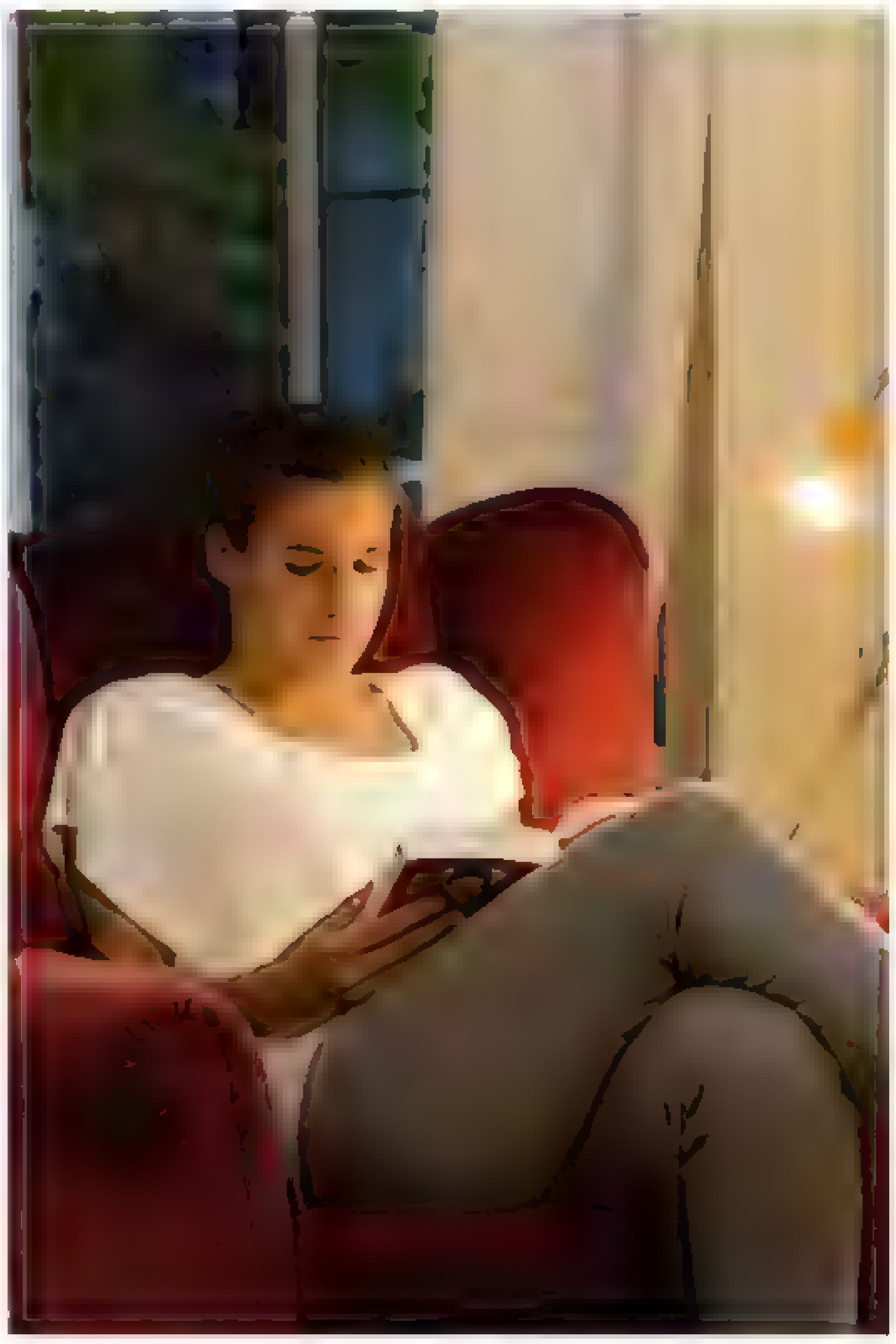
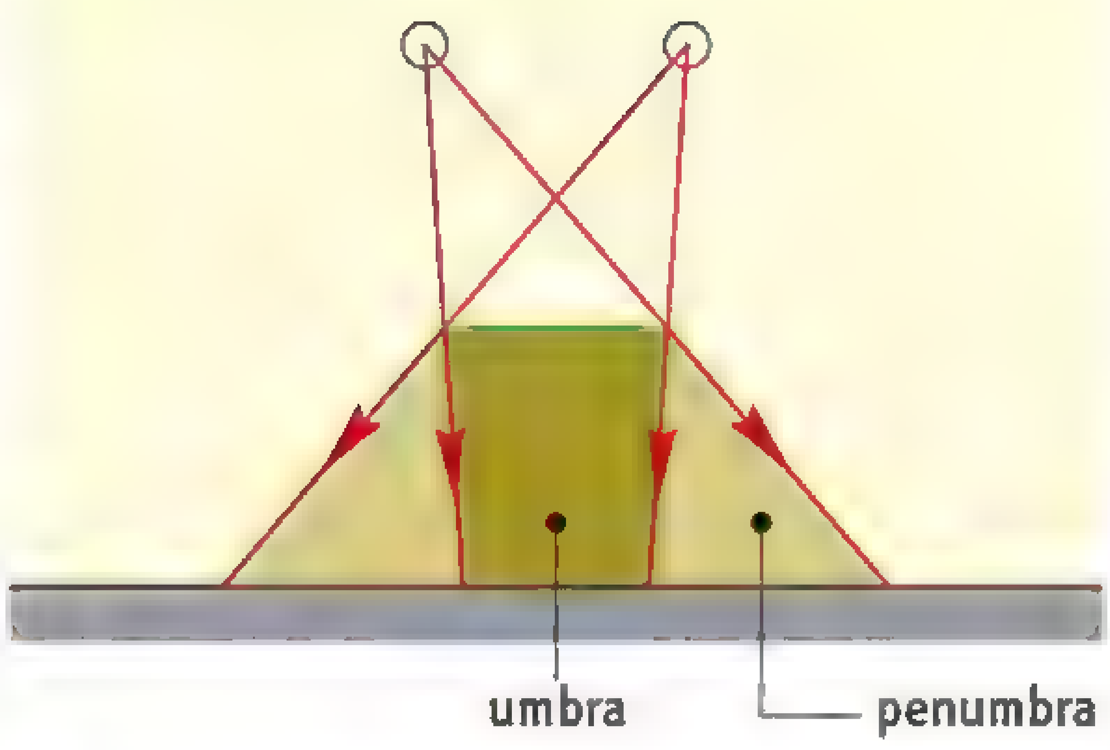


figure 3 A lamp providing direct light.

A reading lamp does not provide appropriate lighting for a worktop surface with tools and other working materials. You then get dark shadows everywhere, with a sharp boundary between light and dark. It can make it difficult for you to see exactly what you are doing. The shadows also distract you from what you really want to be seeing.

Having two lights next to each other can help. You then get double shadows, one from each lamp. The darkest parts of the worktop are where the two sets of shadows overlap. This is called the **umbra.** To the left and right of the umbra, you can see the lighter **penumbra.** Light from one lamp can reach this area but not from the other (figure 4).

figure 4 Umbra and penumbra.



A fluorescent tube gives nice fluid transitions from light to dark. The amount of direct light reaching the worktop decreases gradually in the transitional regions. You can see that the penumbra slowly gets darker until it blends imperceptibly into the umbra.

INDIRECT AND DIFFUSE LIGHT

Lighting is widely used to create a pleasant, inviting atmosphere. The lamps used for this kind of lighting do not give direct light. That is too 'harsh' and business-like. Mood lighting has to illuminate the whole space 'softly', without patches of bright light and deep shadow. This can be done using **indirect light** or diffuse light.

Figure 5 shows you a lamp that gives indirect light. The light from the bulb does not shine directly into the room but is aimed instead at a white wall. The wall reflects the lamplight falling on it in various directions. This makes it seem as if the entire wall is a single illuminating area: an **indirect light source**.

The lamp in figure 6 uses a different method to produce a 'soft' light. The light from the bulb falls on translucent paper that scatters the light in all directions. The ball becomes an indirect light source, just like the wall in figure 5. The light that you obtain this way is called diffuse light.

figure 5 A lamp that provides indirect illumination.

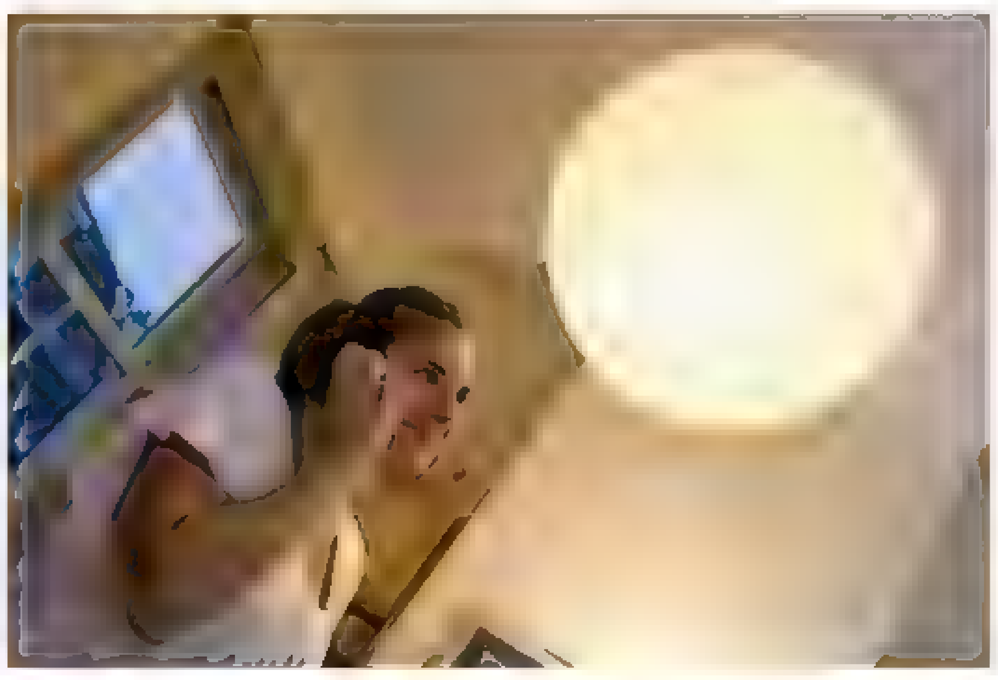


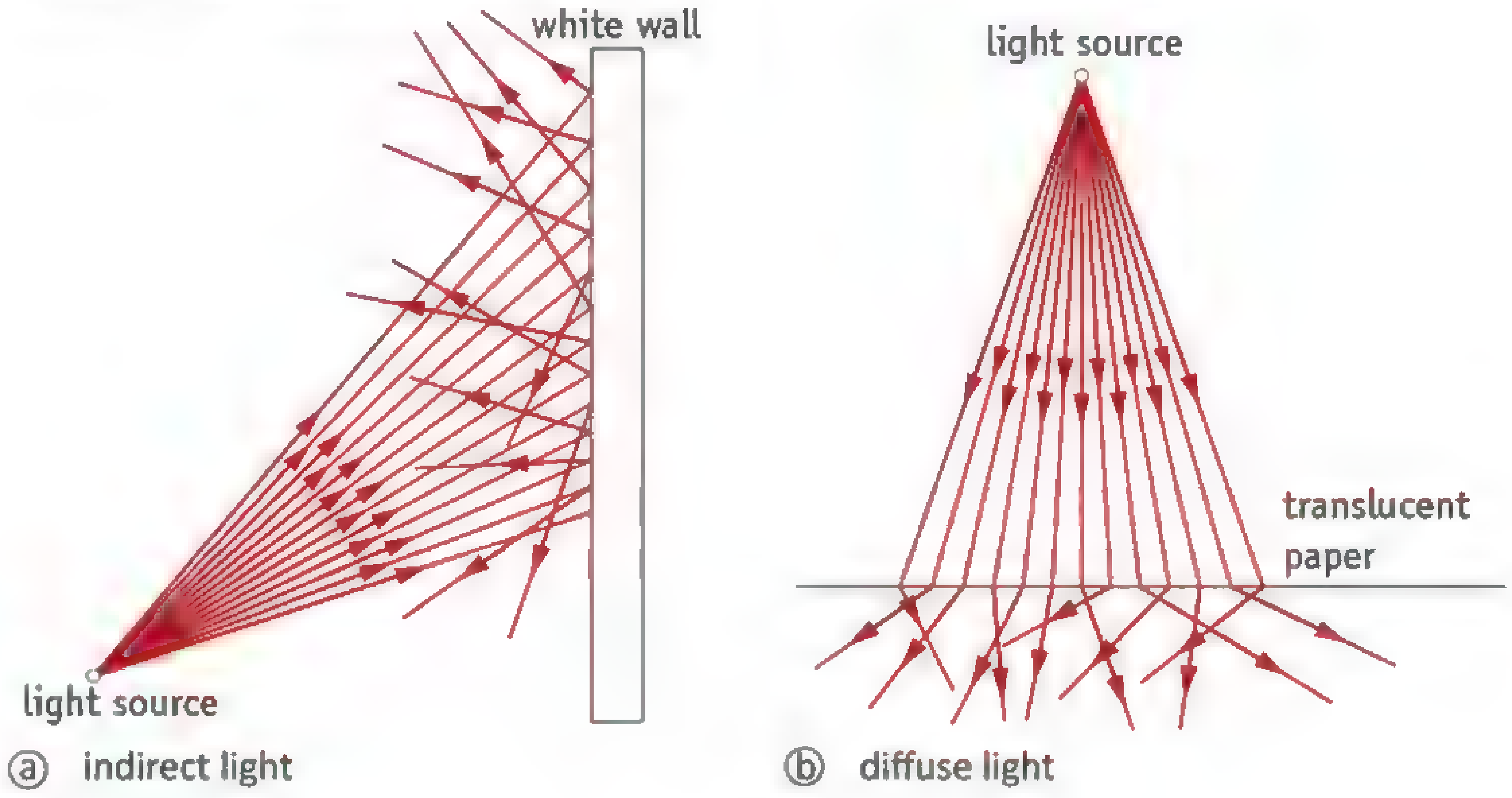
figure 6 A lamp that gives diffuse light.

REFLECTION AND SCATTERING

Indirect light is created by reflection: the light rebounds off a non-translucent surface, such as a white wall. If that surface is not smooth, the light will be reflected from it in all directions (figure 7a). The light is then coming from a larger area and it can reach all kinds of places that the direct light does not get to. This makes the contrast between light and shadow much less.

Diffuse light is created by scattering: the light changes direction as it moves through a translucent material, such as paper, frosted glass or textile (figure 7b).

figure 7 Reflection and scattering.



Reflection and scattering are not merely concepts for lighting technology: they also determine how you perceive the light outdoors. Sand and snow reflect the sunlight that falls on them so that you have to squint with your eyes almost shut. Clouds and mist scatter the sunlight, giving a softened and diffuse light, with almost no shadows.

Practice the concepts using the *Flash cards*.

EXTRA SKY BLUE AND SUNSET PINK

If you look up on a cloudless day, you see that the sky is deep blue everywhere. The light reaching your eyes is perceived as blue. In reality, this blue is a mixture of various spectral colours. There is a lot of violet in it (though your eyes are not so sensitive to that), quite a lot of blue, a bit of green and almost no yellow or red; the mixture of these spectral colours is seen as sky blue.

The blue colour of the sky arises because the molecules in the atmosphere scatter the sunlight (make it change direction). You do not notice that in a thin layer of air. The air then appears perfectly transparent. But in the atmosphere, which is several kilometres thick, the scattering is clearly visible. Violet and blue are the spectral colours that are most strongly scattered, and red and orange are affected least. This means that the scattered light makes the sky blue (figure 8).

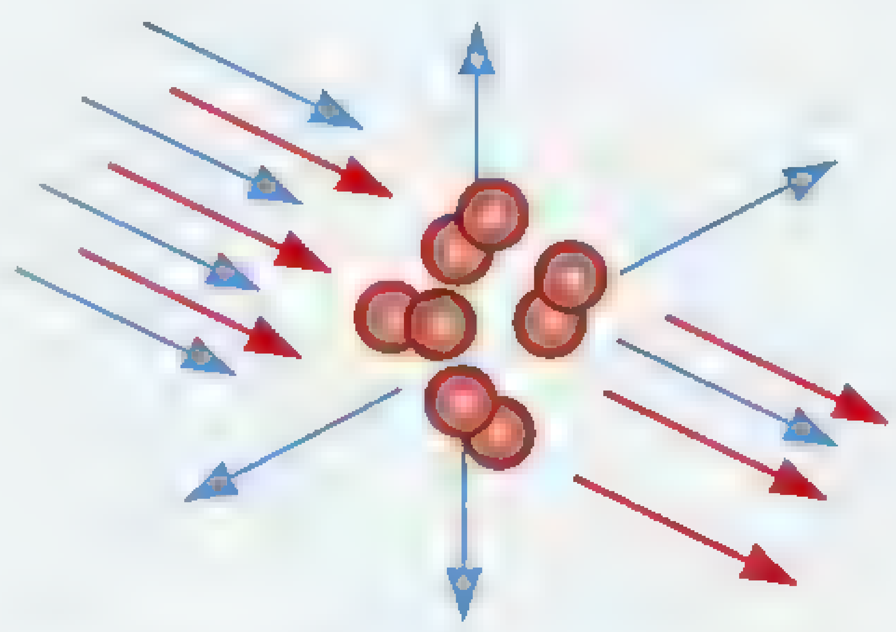


figure 8 Sunlight is scattered by the molecules in the atmosphere.

At sunset, the sunlight has to take a longer path through the atmosphere before getting to your eyes. Almost all the violet and blue light has been scattered out of it by then. Because the red light is scattered much less (and can largely pass straight through the air), it is the dominant colour in the remaining light. That makes the setting sun look red.

COURSE MATERIAL

1 Complete.

a Light rays show you how light moves away from a ....

b Light rays are .... because light moves in .... lines.

c The greater the distance from the light source, the .... the light.

d As the distance from the light source increases, the rays .... (move apart) more and more.

2 A worktop is lit by not one but two lamps hung up next to each other.

a Why does every object on the worktop have two shadows?

b What is the name for the area on the worktop where the shadow is darkest?

c Why are there also two lighter areas of half-shadow?

d What kind of shadows do you get if you replace the lamps with a fluorescent tube?

3 Answer the following questions.

a Why are lamps that give direct light not suitable for creating a pleasant and cosy atmosphere?

b What two types of light are provided by lamps that are used for mood lighting?

c Why do people perceive the light from these kinds of lamps as 'soft'? What does the word 'soft' imply?

IN PRACTICE

4 Figure 9 shows you a bulb hanging above a stool.
Draw in the two edge rays. Hatch in the shadow area between them.

figure 9 The shadow of a stool.

5 Figure 10 shows Peter, who is standing under a streetlight.

a Draw in the bulb of the streetlight at the right place.

b Peter is 1.80 m tall.
How high above the ground is the bulb of the streetlight? Write down step by step how you got your answer.

figure 10 Where is the bulb?

6

Figure 11 shows you a fluorescent tube hanging above a stool, but not directly over it.

a Draw in the two edge rays from the left-hand edge of the fluorescent tube.

b Draw in the two edge rays from the right-hand edge of the fluorescent tube.

c Use blue to show where you can see the umbra of the stool.

d Use red to show where you can see the penumbra areas of the stool.

e A mouse crosses the floor of the room from the left-hand wall to the right, going under the stool. Describe how the light on the floor changes for the mouse as it progresses.

figure 11 The shadow of a stool.

7

In figure 12, you can see a standing lamp and a reading lamp.

a What type of light does lamp 1 give?

b What do you use that light for?

c What type of light does lamp 2 give?

d What do you use that light for?

figure 12 A standing lamp and a reading lamp.

8 Figure 13 shows two portrait photos. The photographer used a flash for both photos.

a Which portrait photo used a very 'harsh' light?
the left-hand photo / the right-hand photo

b How can you see that the light in this photo was 'harsh'?

c How can you see that the light in the other photo was 'soft'?

d Explain why photographers often choose to aim the flash via the ceiling, instead of directly.

figure 13 Two portrait photographs.

9 Explain why:

a you can see the light beams of a laser show much better if it is slightly misty than in dry weather.

b shadows in sunny weather are 'hard' and have sharp edges, whereas you hardly see any shadows if the weather is cloudy.

c people on winter sports holidays have more difficulty with blinding sunlight than tourists hiking round the mountains in the summer.

★ 10 The basic equipment of a professional photographer includes a white umbrella (figure 14).

a What two ways can a photographer use this type of umbrella, according to the text?

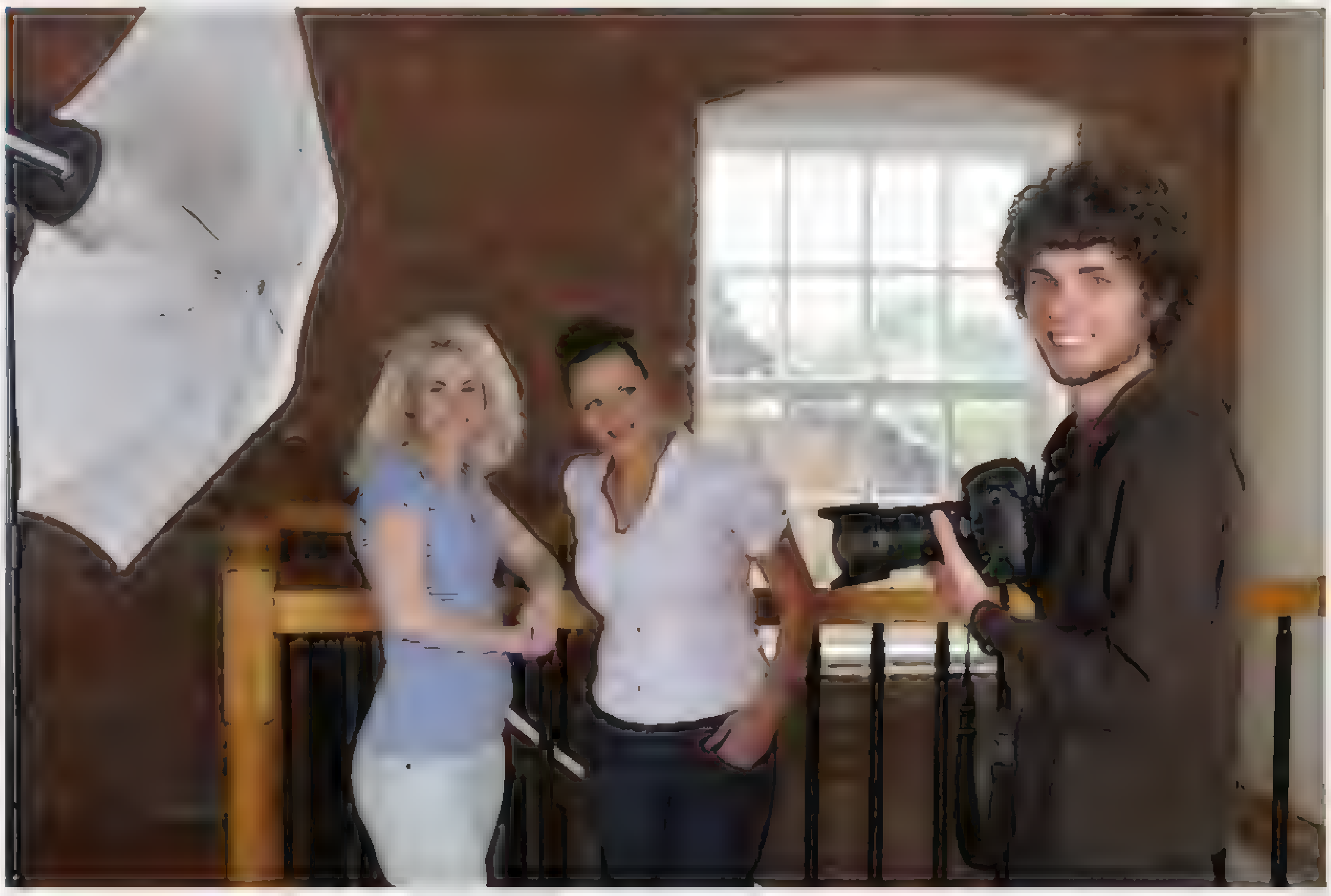
b Which of the two ways is shown on the photo in figure 14? How can you see that?

c Draw how the umbrella, the flash and the model are arranged for the other method.

d The light is softer if the photographer places the umbrella closer to the model. Explain why.

e "A large umbrella produces softer light than a small one," claims a website. Explain whether this statement is correct or not.

figure 14 Part of a photography course.



The umbrella can be used in two ways, namely as a reflector or as a diffuser.
When the umbrella is being used as a reflector, the flash is directed into the umbrella and reflects back onto the model via the open side of the umbrella.
When used as a diffuser, the umbrella is set up with the outside facing the model. The flash is directed into the umbrella in this case as well, but the light now passes through the umbrella fabric and lights the subject.
The bigger the umbrella, the larger the light source illuminating the model.

After: www.123cursus-fotografie.nl

Test what you know with *Test yourself*.

EXTRA SKY BLUE AND SUNSET PINK

11 Answer the following questions.

a Which spectral colours make up the blue of a cloudless sky?
b Why does blue predominate in the light that reaches your eyes from a cloudless sky?
c Why does red predominate in the light that reaches your eyes from the setting sun?

★ 12 A mountain landscape in the distance looks very different to when it is close by (figure 15).

a Describe the differences in colour, contrast and brightness.
b Explain the role that scattering of light has in this.

figure 15 A mountainous landscape.

3 Mirror images

LEARNING OBJECTIVES

6.3.1 You can explain what a mirror image is.
6.3.2 You can describe the law of reflection.
6.3.3 You know two ways of drawing a reflected ray.
6.3.4 You can draw the mirror image of an object.
EXTRA 6.3.5 You can determine the field of view in a mirror.

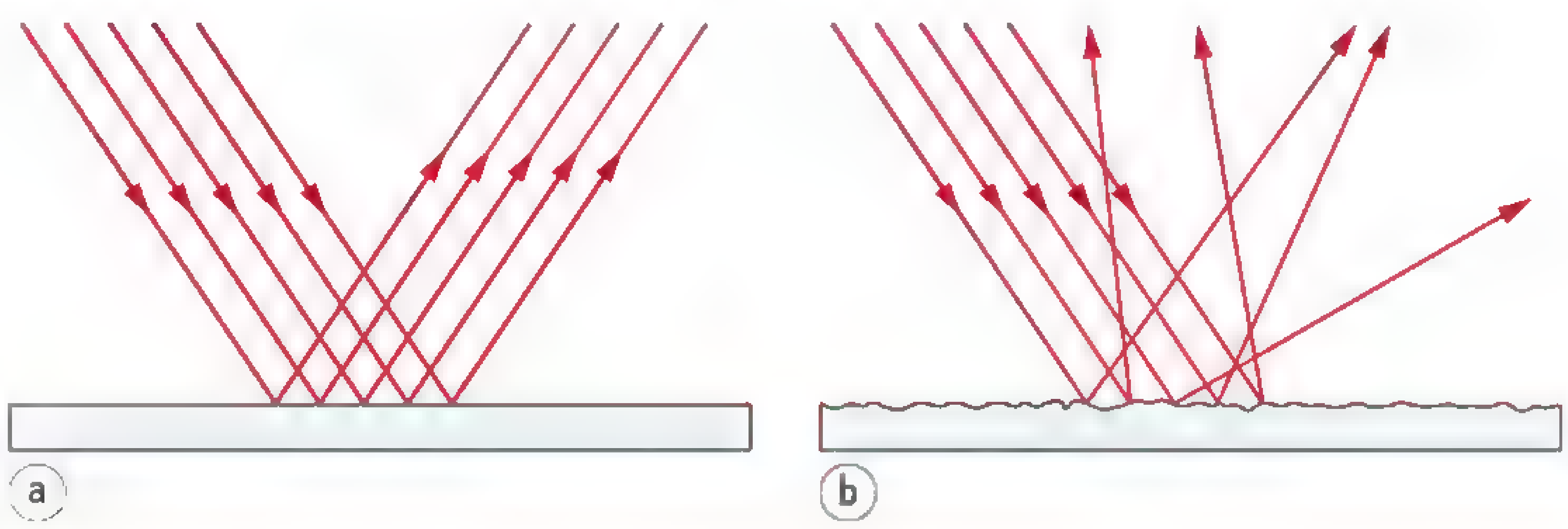
TAXONOMY	LEARNING OBJECTIVES AND EXERCISES				
	6.3.1	6.3.2	6.3.3	6.3.4	6.3.5
Remembering	2a	2bcd	1abcd		
Understanding	3a, 8de		10b		12b
Using	3b		4ab, 5, 10a	9ab	11abc, 12a
Analysing		8abc	6, 7		11d

If sunlight falls on a sheet of white paper or a mirror, more than 90% of the light is reflected. The reflection from the sheet of white paper is diffuse: the reflected sunlight goes in all directions. The light reflected from a mirror, however, bounces back in very specific directions. This is why you can see your face in a mirror but not in a sheet of white paper.

MIRRORS

EXP. 4 A **mirror** consists of a sheet of glass onto which a thin layer of aluminium or silver has been applied. Light passes through the glass and is then reflected by the layer of metal underneath. Because the metal surface is extremely smooth and flat, you get a **mirror reflection:** the light bounces off, but does not do so in all directions as it does in diffuse reflection (figure 1).

figure 1 Mirror reflection (a) and diffuse reflection (b).



If you look in a plane (flat) mirror, you see your **mirror image** 'behind' the mirror (figure 2). The mirror image even has depth: it really does appear to be behind the mirror. When you are holding a mirror, look first at your hand and then at the image of your face. You can feel your eyes having to adjust. The mirror image is further away than your hand.

figure 2 It seems as if there is another world behind the glass, where everything is mirror images.

There is a striking difference between the 'mirror world' and the world in front of the mirror: back and front are reversed. You notice that if you look at a written word in the mirror. You then see that word in mirror writing because you are aeffectively trying to read it from behind. This is the same as if you hold a piece of paper up to the light and try to read the text through it from the back. The opposite is true as well: if you hold mirror writing up to a mirror, the letters then look normal again.

THE LAW OF REFLECTION

EXP. 4

The drawing in figure 3 shows you how a plane mirror reflects a narrow, parallel beam of light. Because you can draw that beam of light as a single ray of light, we generally do say 'ray' for short rather than 'narrow, parallel beam of light'.

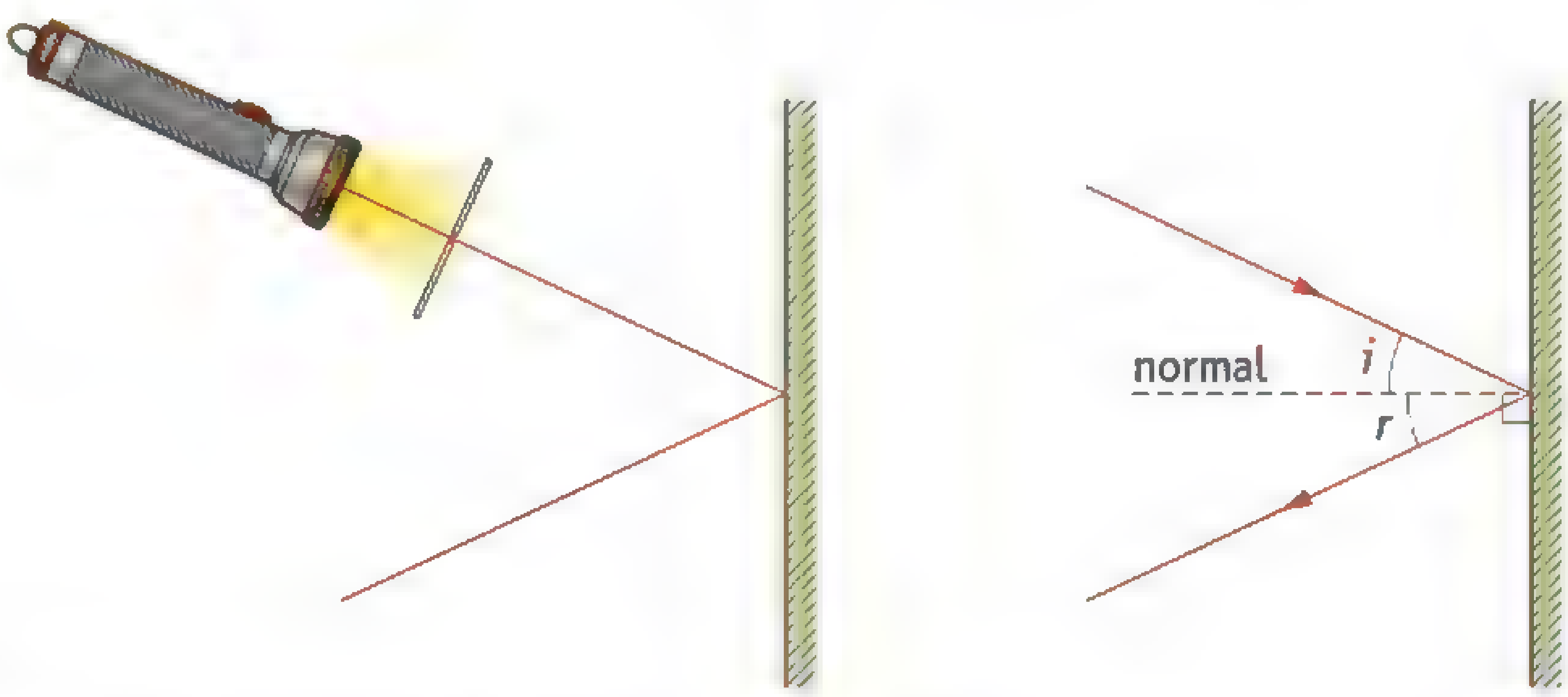


figure 3 This is how light is reflected from a mirror.

A line has been drawn at the point where the ray hits the mirror, at right angles to the mirror: this is called the **normal** or perpendicular. The angle between the incoming ray and the normal is called the **angle of incidence** ($\angle i$). The angle between the reflected ray and the normal is called the **angle of reflection**($\angle r$).

When a mirror reflects light, the rule is always that

angle of incidence = angle of reflection

or in symbols:

$\angle i = \angle r$

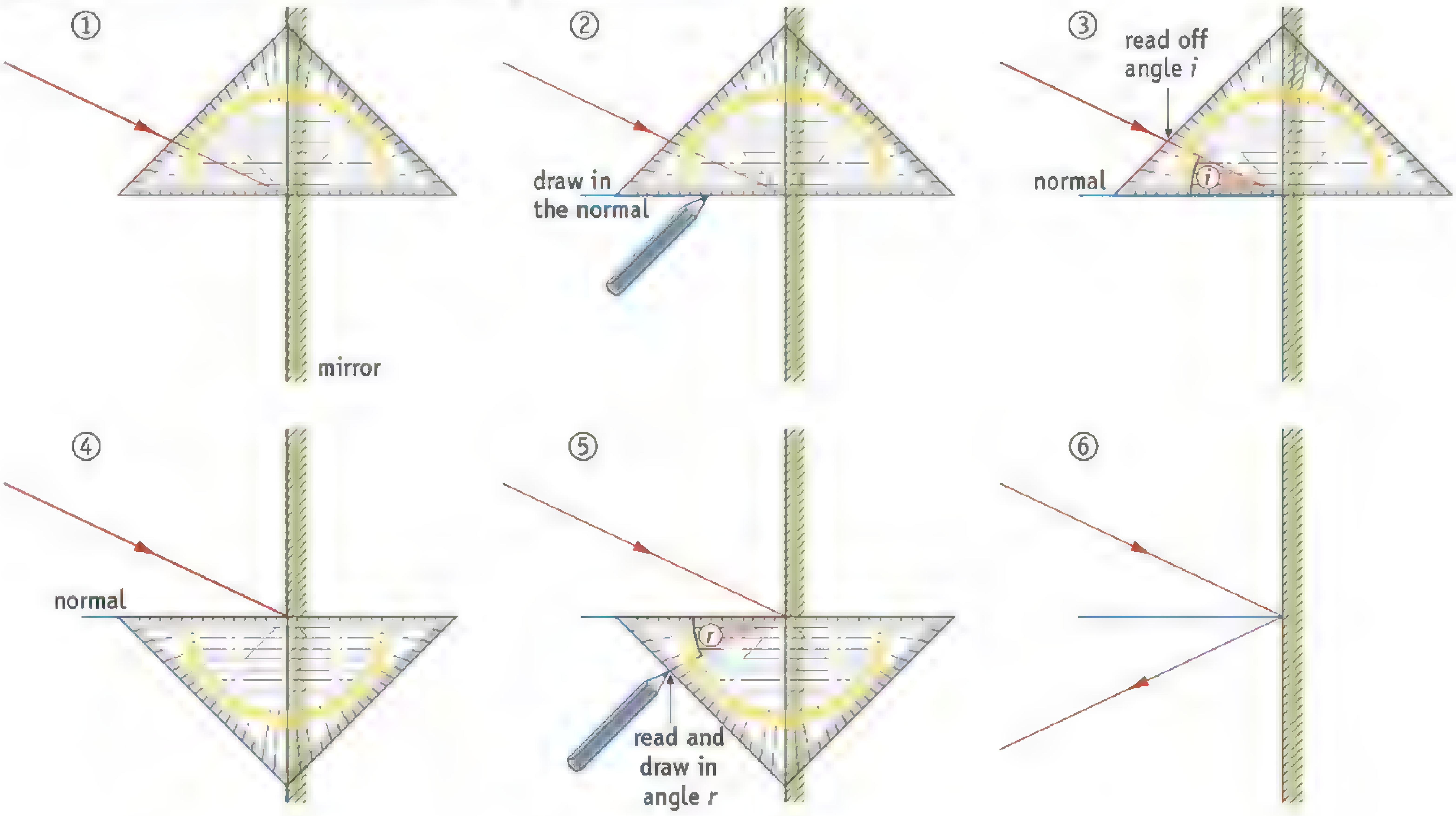
where:
$\angle i$ is the angle of incidence;
$\angle r$ is the angle of reflection in degrees (°).

This rule is known as the **law of reflection.**

You can use the law of reflection to draw how a ray is reflected by the mirror (figure 4):

1 Place your protractor as shown in the drawing.
2 Draw in the normal. The normal is always perpendicular to the plane of incidence (the mirror).
3 Read off the angle of incidence.
4 Now put your protractor on the other side of the normal.
5 Apply the law of reflection and mark in the angle of reflection.
6 Draw in the reflected ray.

figure 4 How to draw in the reflected ray using the law of reflection.



DRAWING THE MIRROR IMAGE

Figure 5 shows a bulb that is in front of a mirror. The reflected rays seem to come from a point that is behind the mirror. If you look in the mirror, that is where you will see the mirror image of the bulb.

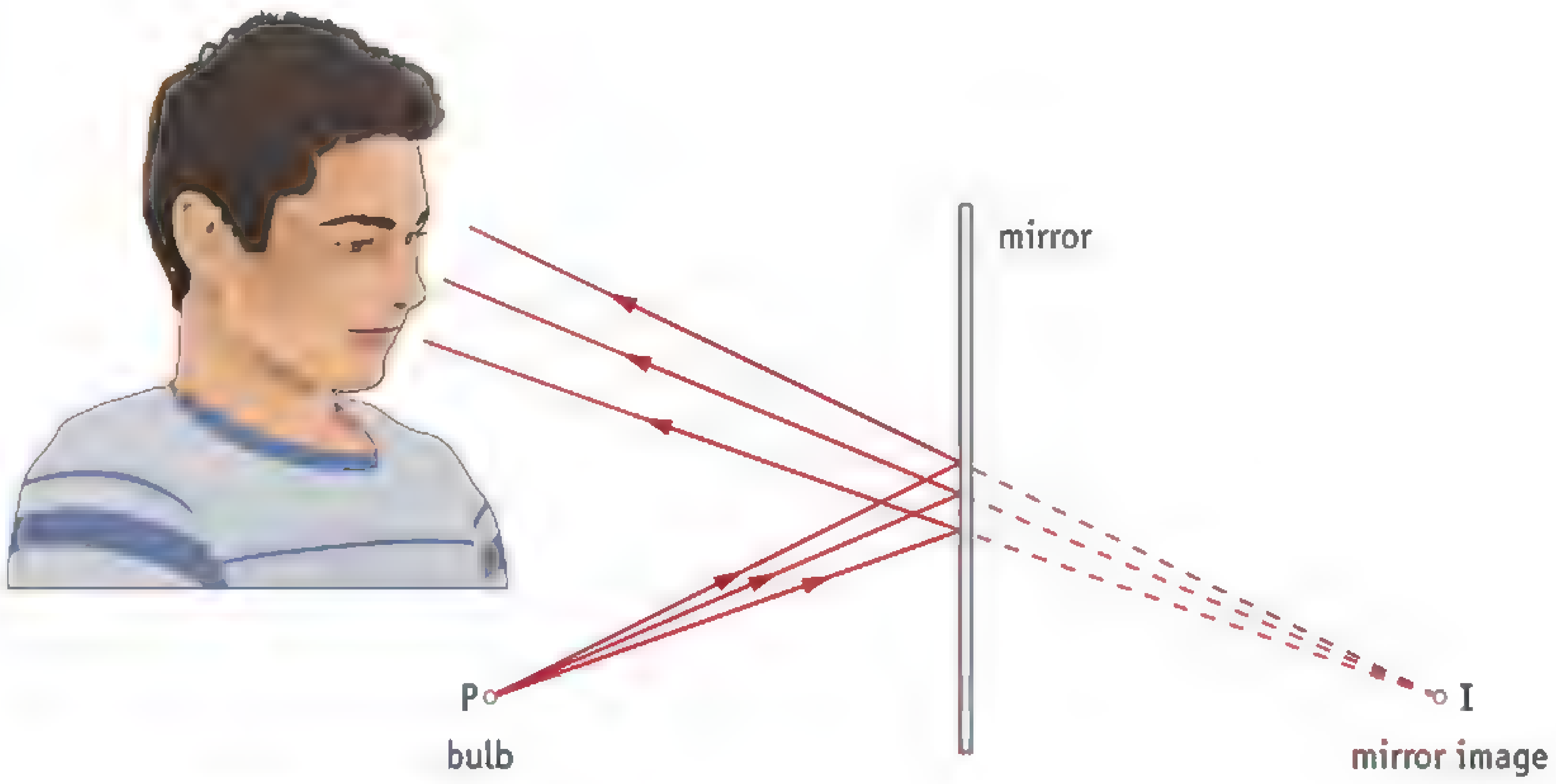
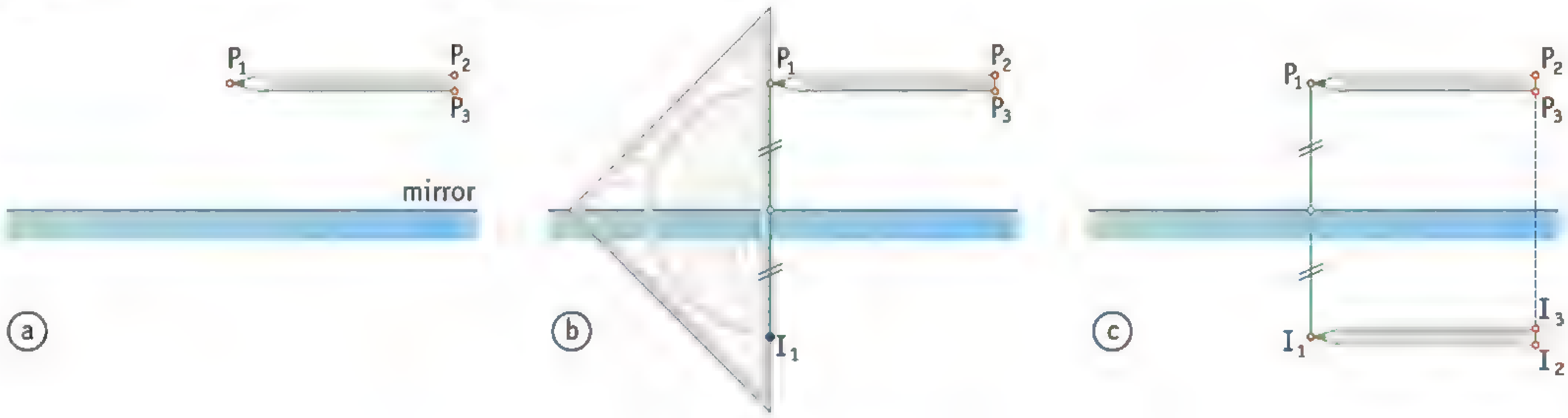


figure 5 Looking at a mirror image.

The mirror image is just as far behind the mirror as the object is in front of it. You can find the location of the mirror image as follows (figure 6):

1 Select a random point P on the object.
2 Place your drafting protractor as shown in the drawing.
3 Draw in an image point I so that I is just as far behind the mirror as P is in front of it.

figure 6 How to draw the mirror image of an object.



You can use this method to determine the mirror image of every point in the object. Number the points of the object P_1, P_2, P_3 and so forth. Number the points of the image I_1, I_2, I_3 and so forth. If a point is not directly in front of the mirror, you may extend the line of the mirror in the drawing to let you find the image point.

DRAWING IN THE REFLECTED RAY

If you want to draw how a mirror reflects the light from source P, you do not have to use the law of reflection. It is usually simpler to start by drawing the image point I for the light source. You can then use the fact that the reflected rays appear to come from point I.

Figure 7 shows you a drawing in which a random ray is reflected by a mirror. To make this kind of drawing, you first mark in the image point for P. This is point I. Then you draw the line *r* starting from I, first as a dashed line behind the mirror, then as a solid line in front of the mirror. The solid part in front of the mirror is the reflected ray.

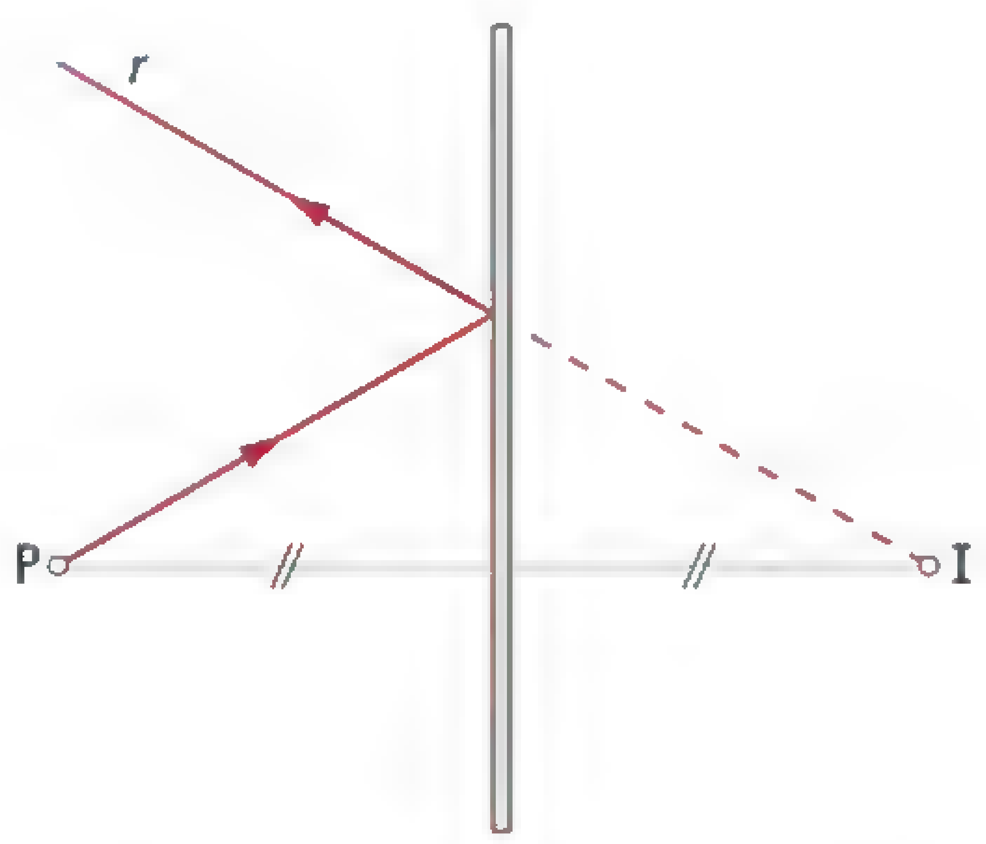


figure 7 How to draw in the reflected ray using the image point.

Practice the concepts using the *Flash cards*.

EXTRA THE FIELD OF VIEW IN A MIRROR

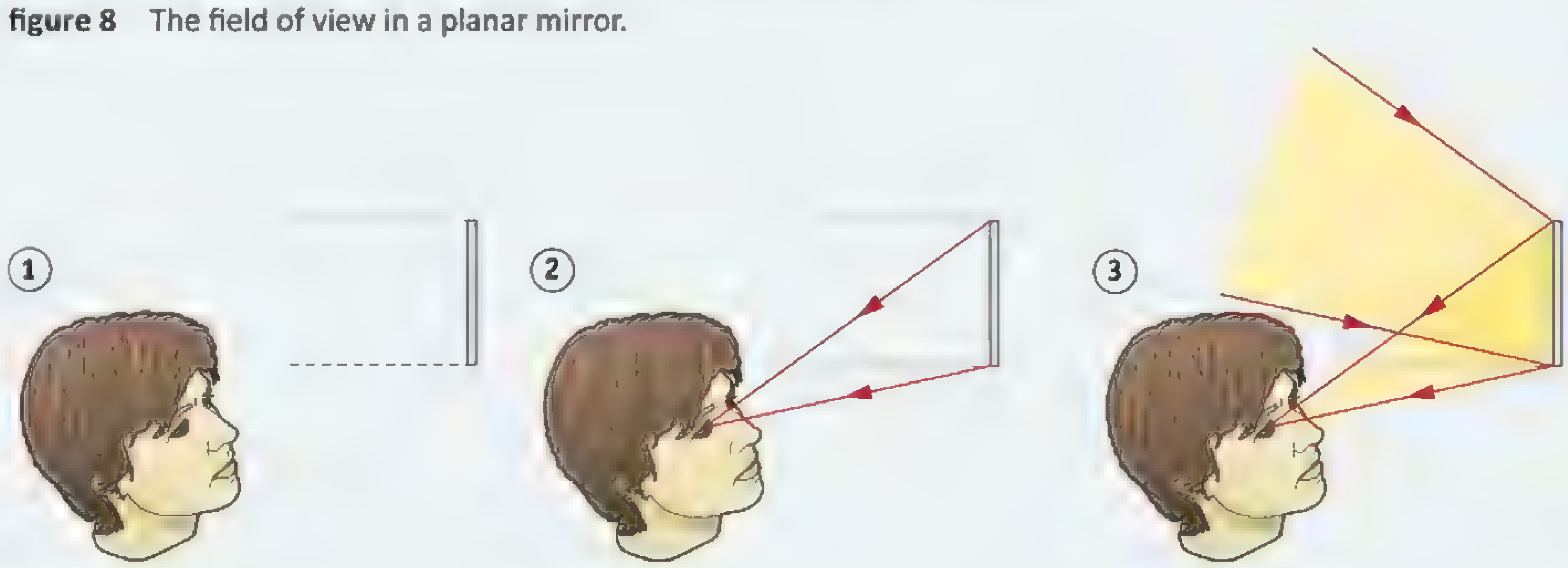
Cars have a rear-view mirror on the inside and two wing mirrors on the outside. The driver can use these mirrors to keep an eye on the road behind and to the sides. A mirror's field of view is the area that you can see in the mirror. The limits of that area are defined by rays that can just get to the driver's eyes from the very edges of the mirror.

You can use the law of reflection to determine the paths of those rays (figure 8).

1 Draw a perpendicular to the mirror surface at both edges.
2 Draw in the two reflected rays going back to the eye.
3 Then use the law of reflection to draw in the two incident rays. The field of view lies between these two rays.

If you want to be able to see as large an area as possible in a mirror, you have to use a convex mirror. Convex mirrors are used in cars, for example, and in trucks (blind spot eliminator mirrors), in supermarkets and at road junctions with poor visibility.

figure 8 The field of view in a planar mirror.



COURSE MATERIAL

1 Make a drawing of a ray that is reflected by a plane mirror. Show in your drawing:

a the direction the ray is going.
b which line is the normal.
c what the angle of incidence is.
d what the angle of reflection is.

2 Answer the following questions.

a What is the difference between mirror reflection and diffuse reflection?
b How can you see that the mirror image appears to be behind the mirror?
c What problem do you encounter if you try to read a piece of text in a mirror?
d Point P is 4.5 cm in front of a mirror.
Where do you draw the image point I?

IN PRACTICE

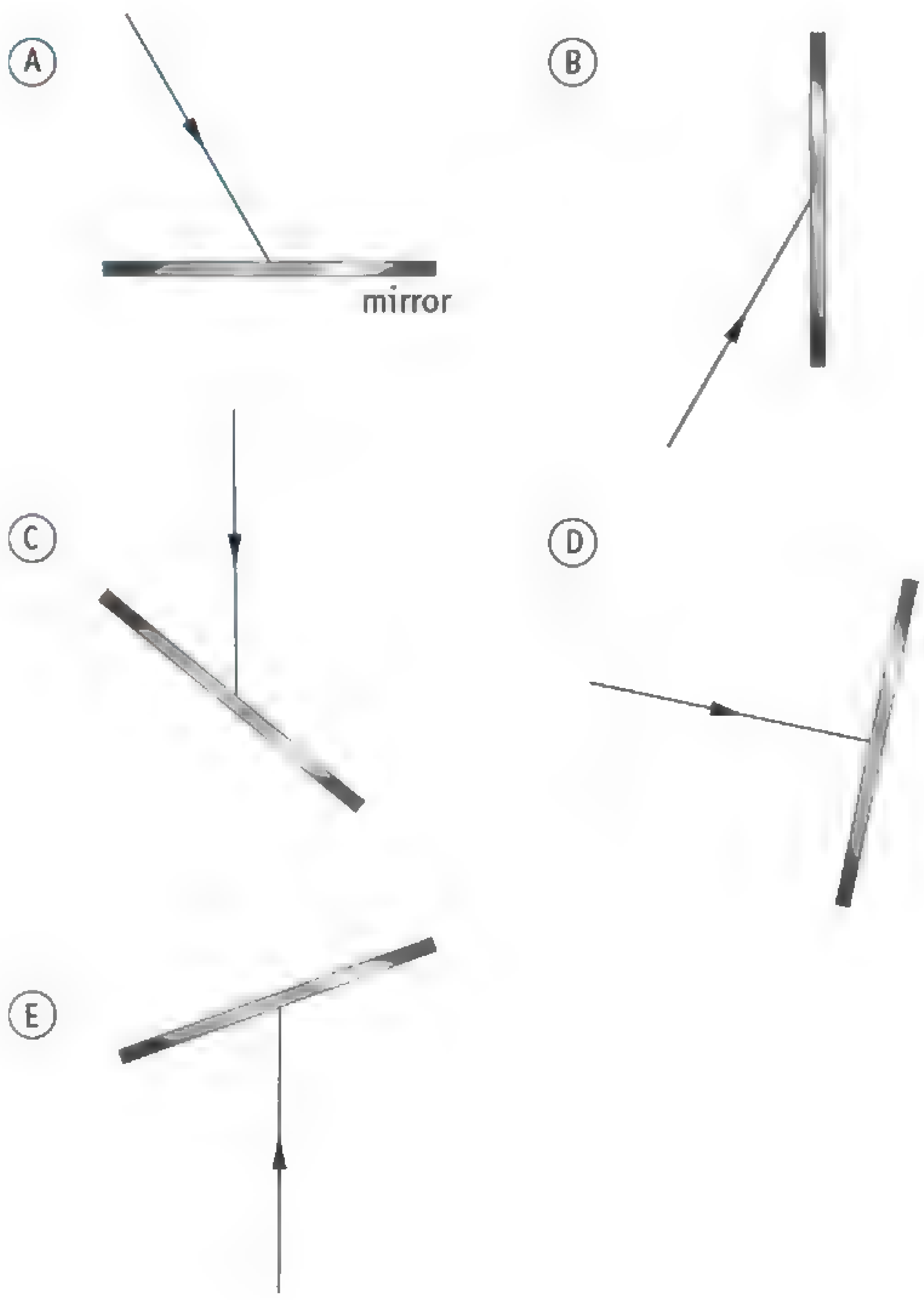
3 The text on a barber's shop window says BARBER as seen from the street.
How does this word appear to one of the barber's customers:

a if he is looking directly out through the window?
b if he is looking out through the window via the barber's mirror?

4 In figures 9a to 9e, draw:

a the normal.
b the reflected ray.

figure 9 Mirror reflection.



5 A beam of light from a pocket torch hits a mirror (figure 10).
Draw in how the beam of light is reflected.

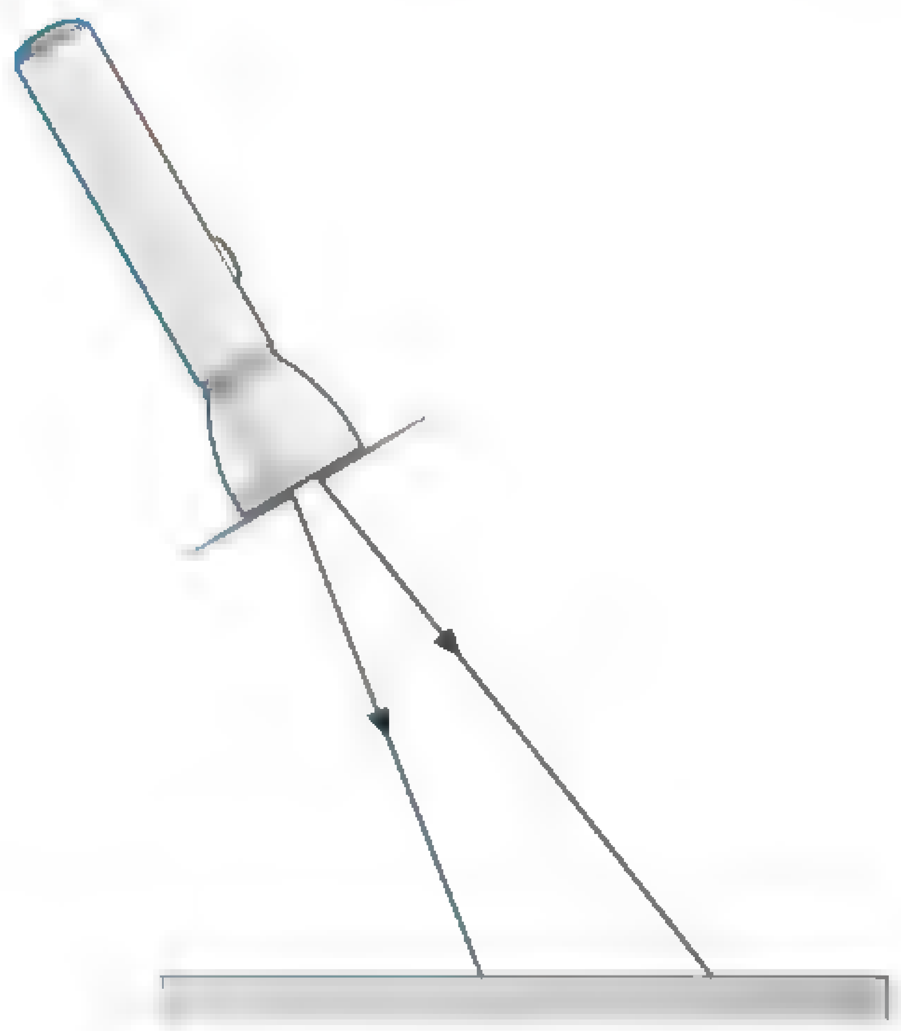


figure 10 Reflections for a pocket torch.

★ 6 A solar energy generator consists of a large number of plane mirrors that are intended to reflect sunlight into a furnace. The mirrors are on poles. You can see the furnace in figure 11, along with three poles (the mirrors have not yet been drawn) and the direction of the sunlight.
Draw the orientations in on the figure for positioning the mirrors so that the light from the sun is reflected into the middle of the furnace.

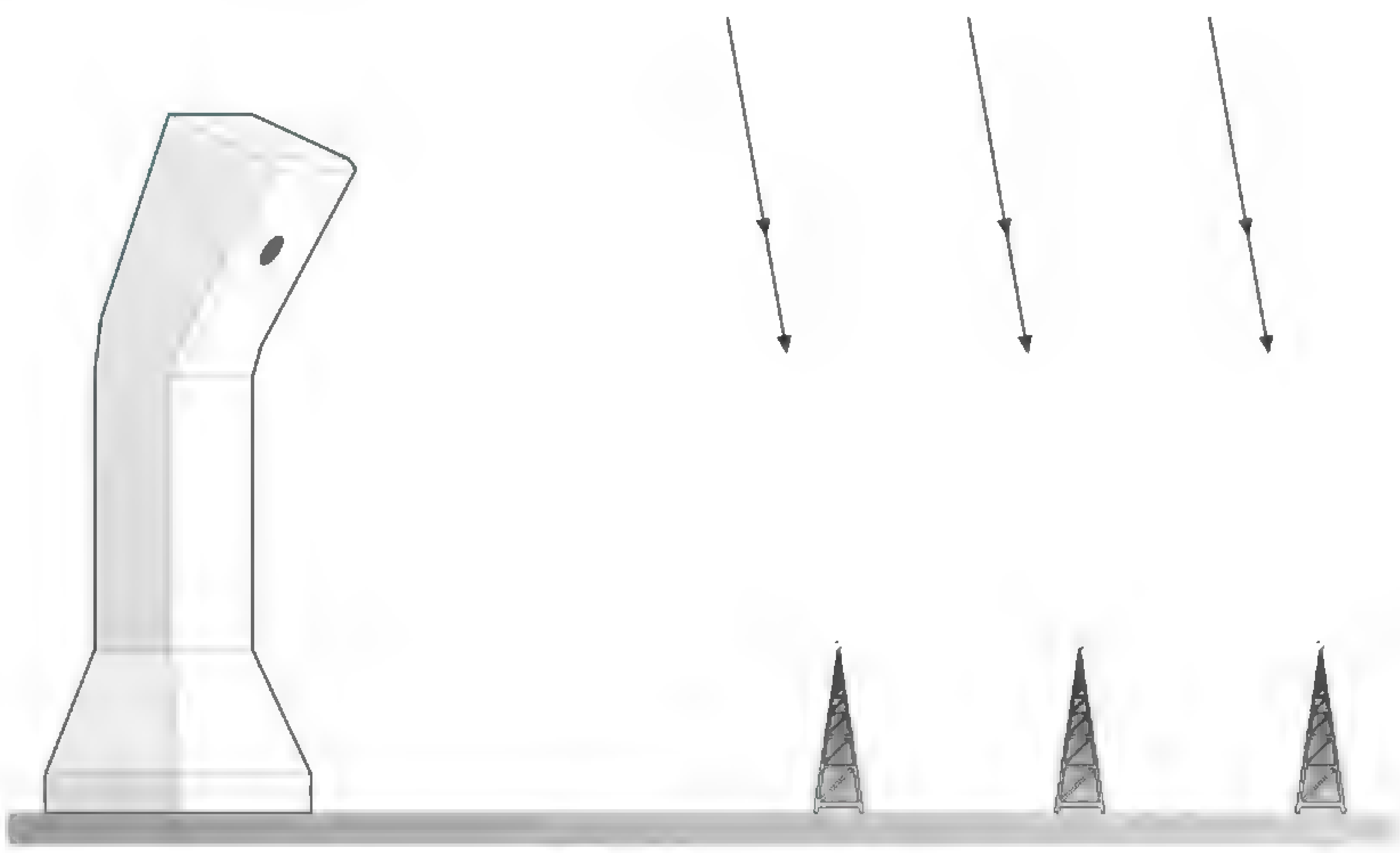


figure 11 The mirrors of a solar energy plant.

7 Miriam and Liz are standing in front of a large, reflecting shop window. This is shown from above in figure 12.
Make an accurate drawing that shows clearly whether they can see each other in the window. Explain your answer. Tip: draw the mirror images of Miriam and Liz first.

figure 12 Miriam and Liz in front of a reflective shop window.

★ 8 Look at the photograph of the sunset in figure 13.

a Explain how the narrow strip of light appears that you can see running across the water.
b Explain why that strip of light always appears to be coming straight towards the observer.
c Explain what causes the darker stripes that interrupt the strip of light.
d Just occasionally, you can see the mirror image of the setting sun in the sea, instead of a strip of light such as that shown in figure 13.
What is needed for you to be able to see a perfectly reflected, round disc of the sun?
e Why are you more likely to be able to see the mirror image of the setting sun in a lake than in the sea?

figure 13 A reflected sunset.

9 Jack is looking at himself in a mirror (figure 14).

a Draw the image points of:

- the top of his head (P_1);
- his right eye (P_2);
- the tip of his nose (P_3);
- his chin (P_4);
- the back of his head (P_5);
- the collar (P_6).

b Now sketch in the mirror image of his face.

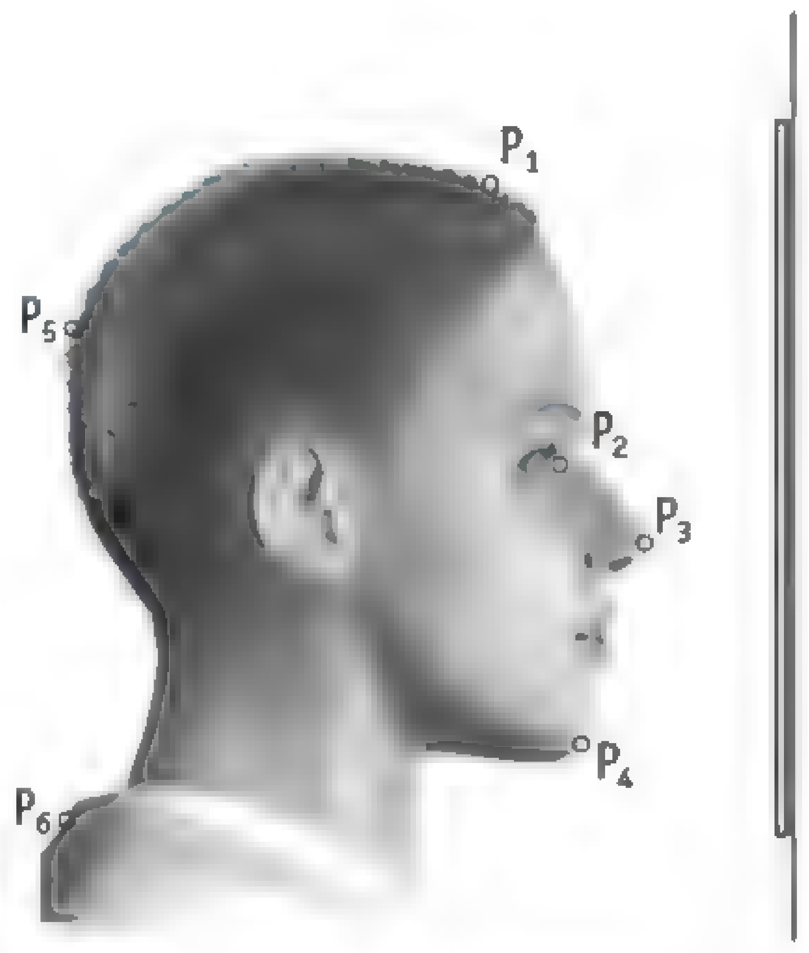


figure 14 Mirror reflection.

10 Robin is trying to find his way through a laser maze (figure 15). The laser beam is reflected by small mirrors each time. The idea is that Robin must not break the laser beam. If he does, an alarm will sound.

Figure 16 shows you a top view of Robin in the laser maze.

a Draw in the rest of the path of the laser beam. The beam starts at point P.

b Does the alarm go off?

figure 15 You have to be able to keep your balance well in a laser maze.

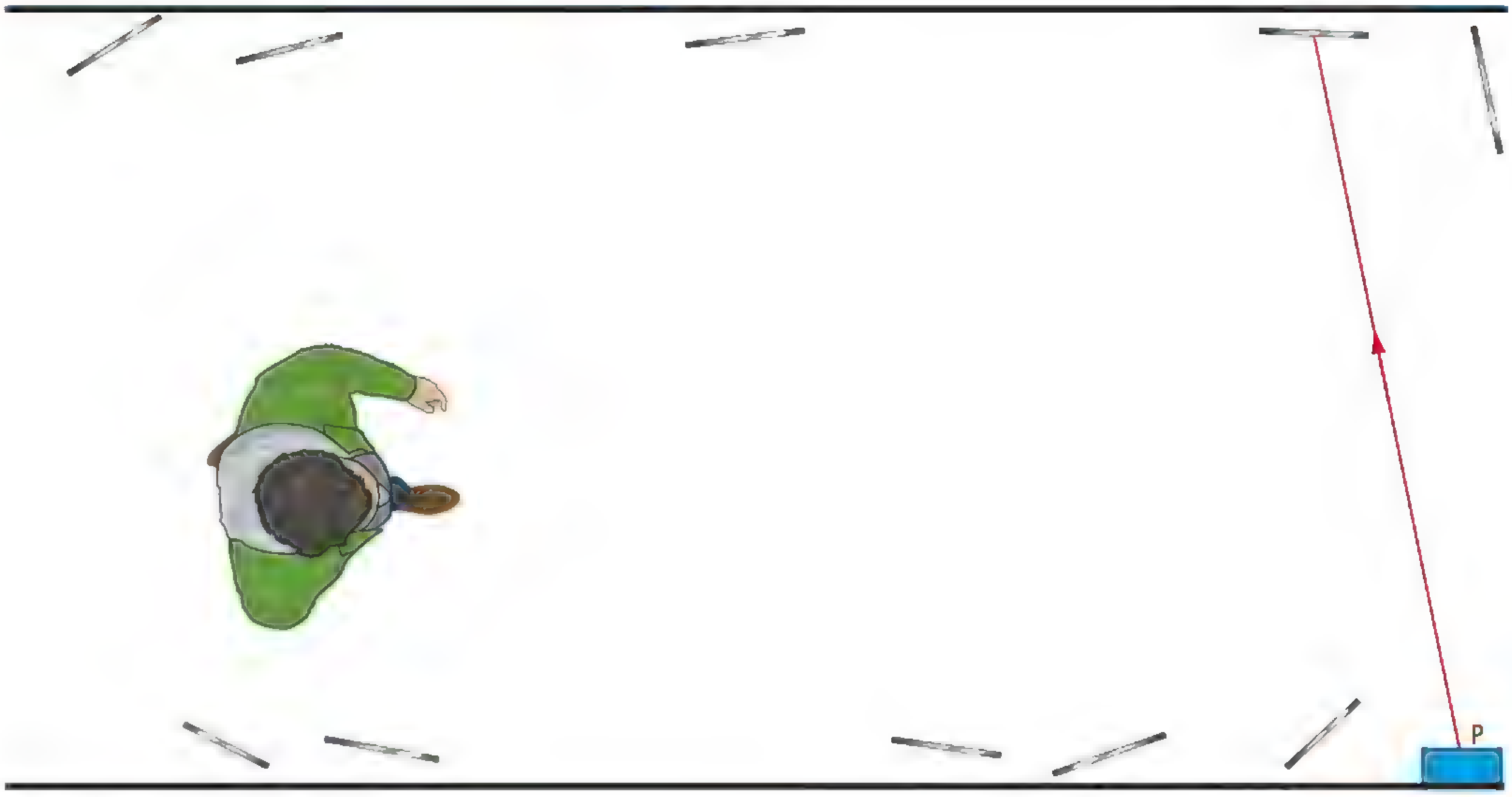


figure 16 Will the alarm sound?

Test what you know with *Test yourself*.

EXTRA THE FIELD OF VIEW IN A MIRROR

11 A car driver (shown in figure 17 as point A) first looks in his car's rear-view mirror and then in the wing mirrors.

a Colour in the area that he can see in the rear-view mirror in blue.

b Colour the area that he can see in the left wing mirror in green.

c Colour the "blind spot" area in red.

d How can he make sure that he is also able to see other road users who are in the blind spot?

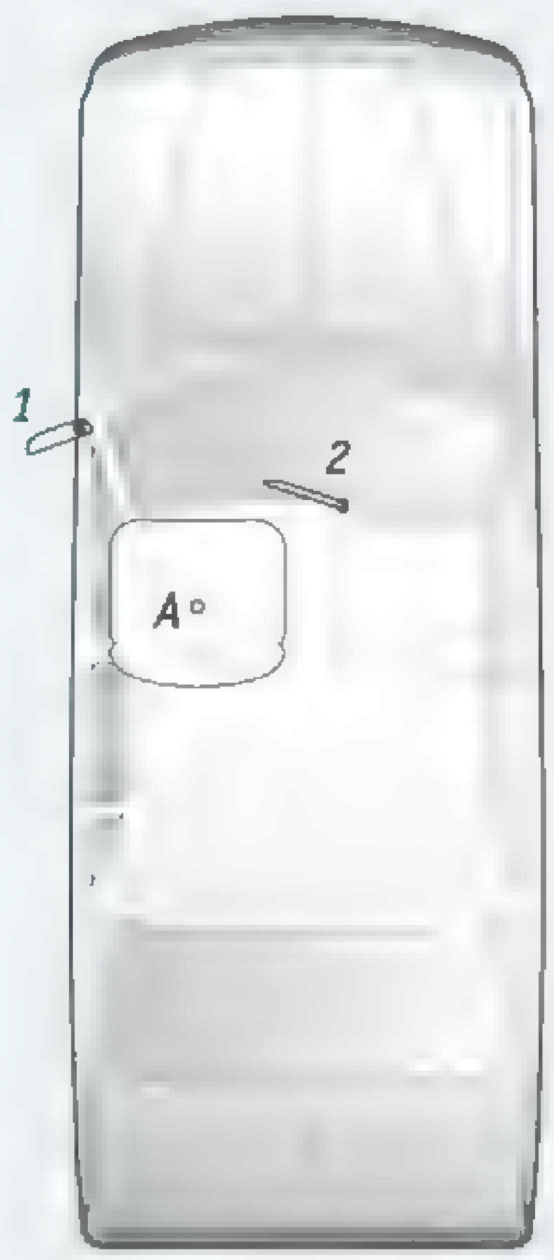


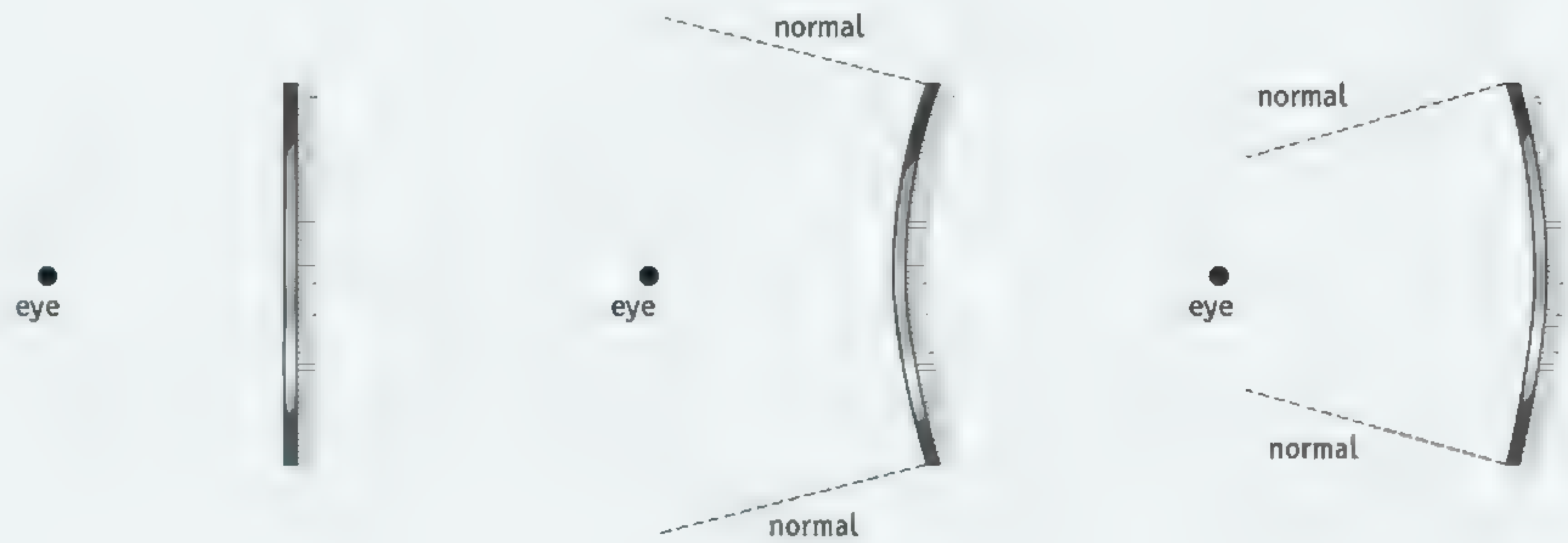
figure 17 What can a car driver see in his mirrors?

12 The three mirrors in figure 18 each have a different field of view.

a Construct the fields of view of each of the three mirrors.

b Which mirror lets you see the widest area?

figure 18 The fields of view of three mirrors.



4 Infrared and ultraviolet radiation

LEARNING OBJECTIVES

6.4.1 You can describe where infrared and ultraviolet radiation are located in the spectrum.
6.4.2 You can describe the features of infrared and ultraviolet radiation.
6.4.3 You can write down some applications of infrared and ultraviolet radiation.
6.4.4 You can explain what the dangers of UV radiation are.
EXTRA 6.4.5 You can write down the characteristics of three types of UV radiation.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	6.4.1	6.4.2	6.4.3	6.4.4	6.4.5	6.1.3*
Remembering	2b	1ad	1b, 3abcd	1c	10abcd	2a
Understanding		4abc, 5abc, 6ac, 7a		9b	11a	
Using		4d, 6b		8, 9ac	11b	7bc
Analysing					12ab	

* You can find this learning objective in an earlier section.

The sun emits more than just light: it also produces infrared and ultraviolet radiation. These types of radiation are very similar to light. You do not notice them, however, because your eyes are not sensitive to them. That is not the case for all animals, though. Many birds, for example, can see ultraviolet radiation very well.

INFRARED RADIATION

All the objects around you – including humans and animals – are sources of infrared radiation (IR). The higher the temperature of the object, the more radiation it emits. You will notice this if you hold your hand close to a hot radiator, for instance. You can feel that your hand is getting warm as it absorbs the infrared radiation from the radiator.

Heat lamps give off a little bit of red light that you can see, but primarily a lot of infrared. They are used a lot for keeping new-born animals warm (figure 1), but you also come across them as patio heaters and in infrared saunas. Humans and animals perceive the radiation emitted by these lamps as 'pleasantly warm'.

figure 1 Newly-hatched chicks under the heat lamp.

If you make a spectrum of a heat lamp, you will find the infrared radiation next to the red. To prove this, you can use a sensor that is sensitive to infrared radiation. There are also infrared cameras that let you take photographs using infrared radiation. The name 'infrared' literally means 'below the red'.

APPLICATIONS OF INFRARED

Infrared is also used for remote controls. The remote contains a LED that produces infrared radiation. When you press one of the buttons, the LED emits 'flashes' of infrared. This signal is picked up by an infrared sensor in the device and it can then be processed by the electronics.

Infrared radiation is also used in automatic switches. The sensor in a porch light, for example, responds to infrared radiation emitted by people walking by. The sensor then switches the current so that the lamp is turned on (figure 2).

figure 2 A porch light with an infrared sensor.

You also find infrared sensors in alarm installations and in shop doors that open and close automatically. The military use night vision goggles that convert invisible infrared radiation into visible light.

ULTRAVIOLET RADIATION

When you lie in the sun, your skin receives **ultraviolet radiation** (UV) as well as light. Your skin responds to that by producing additional pigment: you get a tan. The pigment that gives you a tan has a protective effect. This is why you can stay in the sun for longer once your skin has darkened a bit.

If you get too much ultraviolet radiation on your skin, you may get sunburnt. Your skin then becomes red and painful. This is a sign that your skin cells have been damaged. This is not only uncomfortable but also a health risk: too much ultraviolet increases the risk of skin cancer. This is why people are asked to be sensible in the sun (figure 3).

figure 3 A cap or hood protects the sensitive skin of the face against UV radiation.

Sun cream contains a UV filter that blocks out some of the ultraviolet radiation. If you use sun cream, you get sunburnt less quickly. The packaging states the protection factor. This number states how many times longer you can stay in the sun. A cream with factor 10, for instance, means you can sunbathe for ten times as long. If you would be able to sunbathe for 5 minutes without a cream, you would be able to have $10 \times 5 = 50$ minutes with this cream.

UV LAMPS

EXP. 7

There are also lamps that produce primarily ultraviolet, such as the **UV lamps** in a solarium or blacklights in a disco. As well as ultraviolet radiation, these lamps do produce a bit of violet light. You can recognize UV lamps and blacklights by this violet light.

If you make a spectrum of a UV lamp, you will find the ultraviolet radiation next to the violet. You can show this by measuring the amount of ultraviolet radiation using a UV sensor. The name 'ultraviolet' literally means 'beyond the violet' (figure 4).

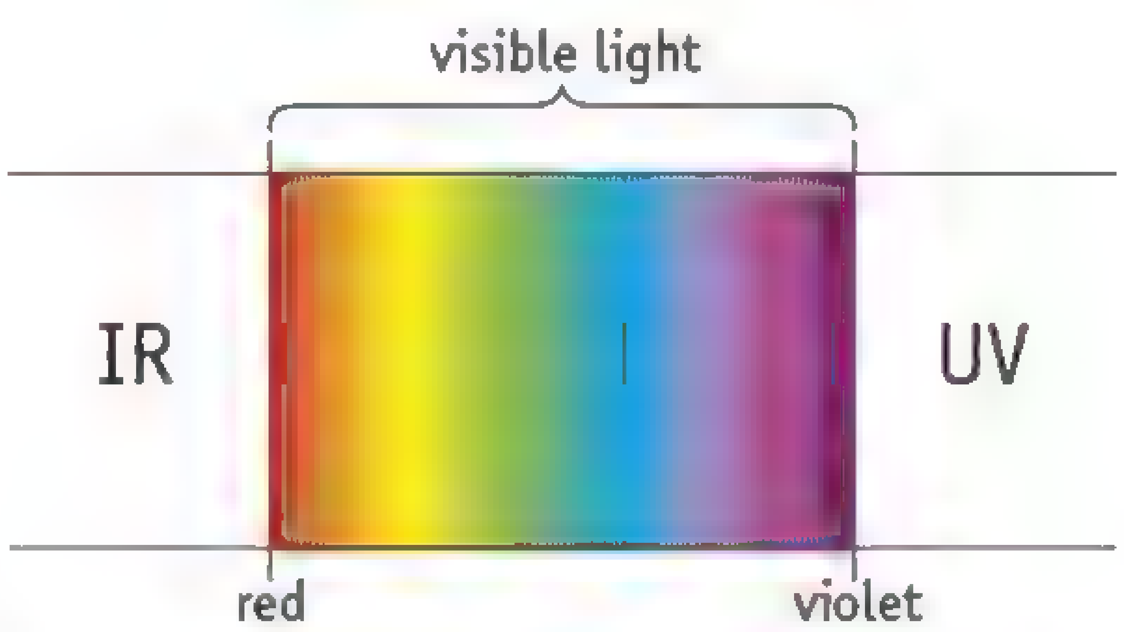


figure 4 Where infrared and ultraviolet radiation are in the spectrum.

Ultraviolet radiation can make some substances light up brightly. This is known as **fluorescence**. Fluorescent materials are used in fluorescent tubes and banknotes, among other things. Under a UV lamp, the fluorescent ink in a genuine banknote lights up clearly; a forgery that does not use fluorescent ink will not do that (figure 5).

figure 5 A banknote being checked under a UV lamp.

Practice the concepts using the *Flash cards*.

EXTRA THREE TYPES OF ULTRAVIOLET RADIATION

The main source of ultraviolet radiation on Earth is the sun. All UV radiation is harmful to the skin (figure 6). UVA and UVB radiation can penetrate through the skin. UVC radiation does not reach the Earth's surface.

- Most of the ultraviolet radiation is UVA. This type of radiation is not blocked by clouds or glass and is present all year round. It makes the skin age, causing wrinkles, spots and melanomas (the most dangerous form of skin cancer). UVA radiation also makes fabrics and pigments discolour.
- UVB radiation is just a small fraction (about 2%) of all the ultraviolet radiation. In the Netherlands, this type of radiation peaks at between 12:00 and 15:00. UVB radiation tans the skin and makes it produce vitamin D. But UVB radiation from the sun also damages the outermost layer of the skin, gives you sunburn and increases the risk of skin cancer.
- UVC radiation is blocked by the ozone layer and so it doesn't reach the Earth's surface. Which is just as well, because this type of radiation is very hazardous for the skin and the eyes. UVC radiation converts oxygen into ozone and helps maintain the ozone layer.

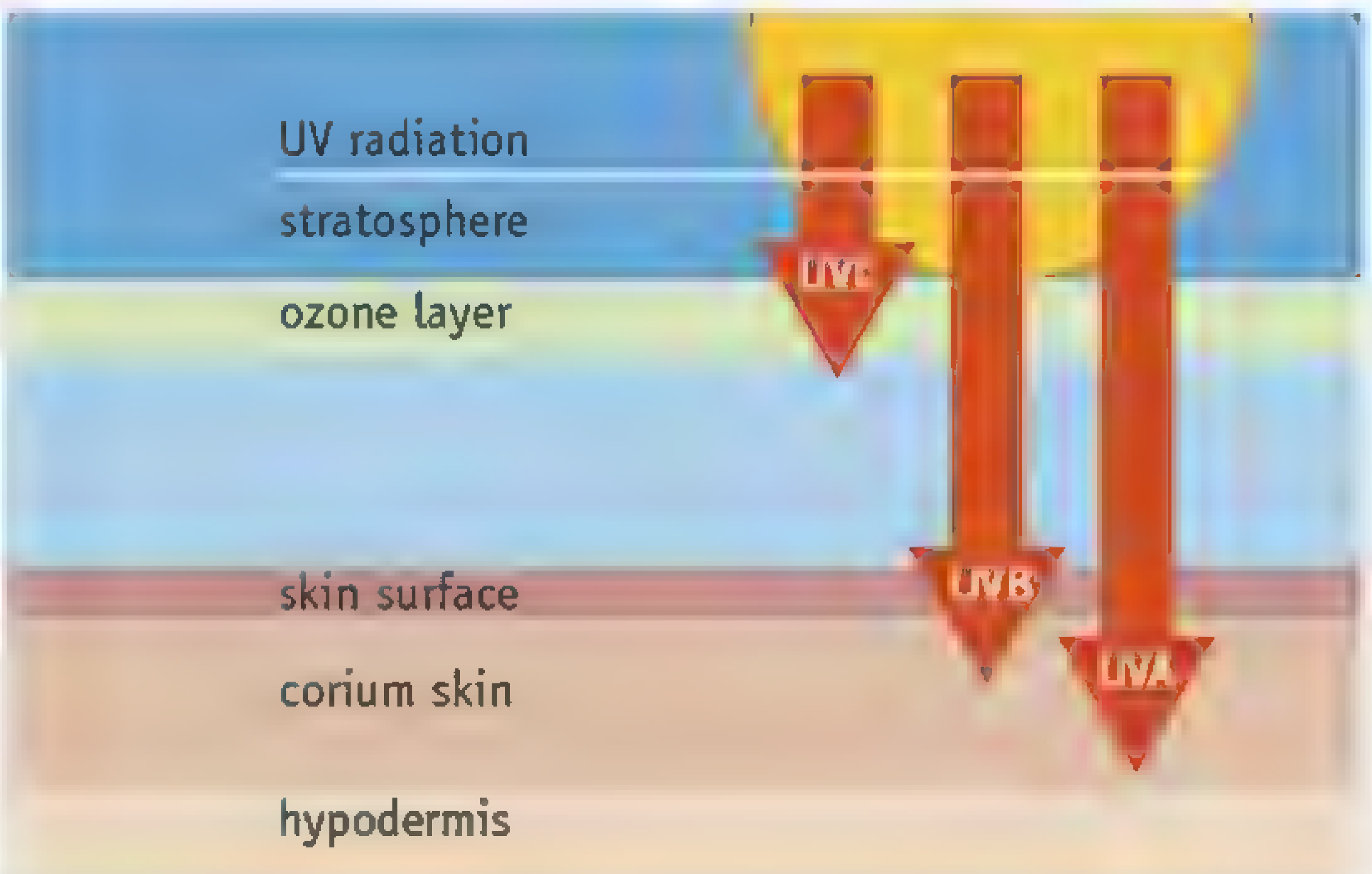


figure 6 All ultraviolet radiation is harmful to the skin.

COURSE MATERIAL

1 Answer the following questions.

- a How can you tell that a hot radiator is emitting infrared radiation?
- b How does a remote control pass your commands on to the device?
- c What type of radiation do UV lamps emit, in addition to a lot of ultraviolet radiation?
- d What do you see when a fluorescent material is illuminated by ultraviolet radiation?

2 You can use a prism to split the radiation from the sun to create a spectrum.

- a Draw a diagram show the spectrum of sunlight, with the various colours in their correct places.
- b Indicate where you can find the sun's ultraviolet and infrared radiation in this spectrum.

3 Four sources of infrared or ultraviolet are listed below.
Which sort of radiation (IR or UV) is emitted by:

a a blacklight? *IR radiation / UV radiation*
b a patio heater? *IR radiation / UV radiation*
c a heat lamp? *IR radiation / UV radiation*
d a sunbed? *IR radiation / UV radiation*

IN PRACTICE

4 If you heat a patio with an infrared lamp (figure 7), people sitting there will be less affected by the cold.

a Fergus says that it's nice and warm on the patio because the IR radiation is making the air there warmer. Explain whether Fergus is right or not.
b Figure 8 shows a different kind of patio heater. This is heated up by burning gas. The heating elements have caps around them with reflective interiors.
What does the inside of the cap have to reflect?
c What goes wrong if the element does not have a cap like this?
d There is also a reflecting cap on top of the IR patio heater. What is it needed for?

figure 7 An infrared lamp for patio heating.

figure 8 Patio heating by gas.

5 Humans, animals and objects get warmer when they absorb infrared radiation.
Explain why:

a people gathered around a campfire feel the warmth on their faces, while their backs remain cold.
b a chicken cooking under a grill has to be turned regularly if it is to be browned evenly all over.
c moving your chair back 1 m helps if you are uncomfortably hot when close to an open hearth.

6 An incandescent bulb converts electrical energy into various sorts of radiation. Figure 9 shows how the energy consumed is distributed across the various types of radiation emitted.

a What shows you that an incandescent bulb is not very energy-efficient?

b Sketch in figure 9 what the graph would look like for a perfectly efficient bulb.

c Energy-saving lamps and LED lights are much more efficient in the way they use energy.
Explain how you can tell that if you put your hand close to these types of lights.

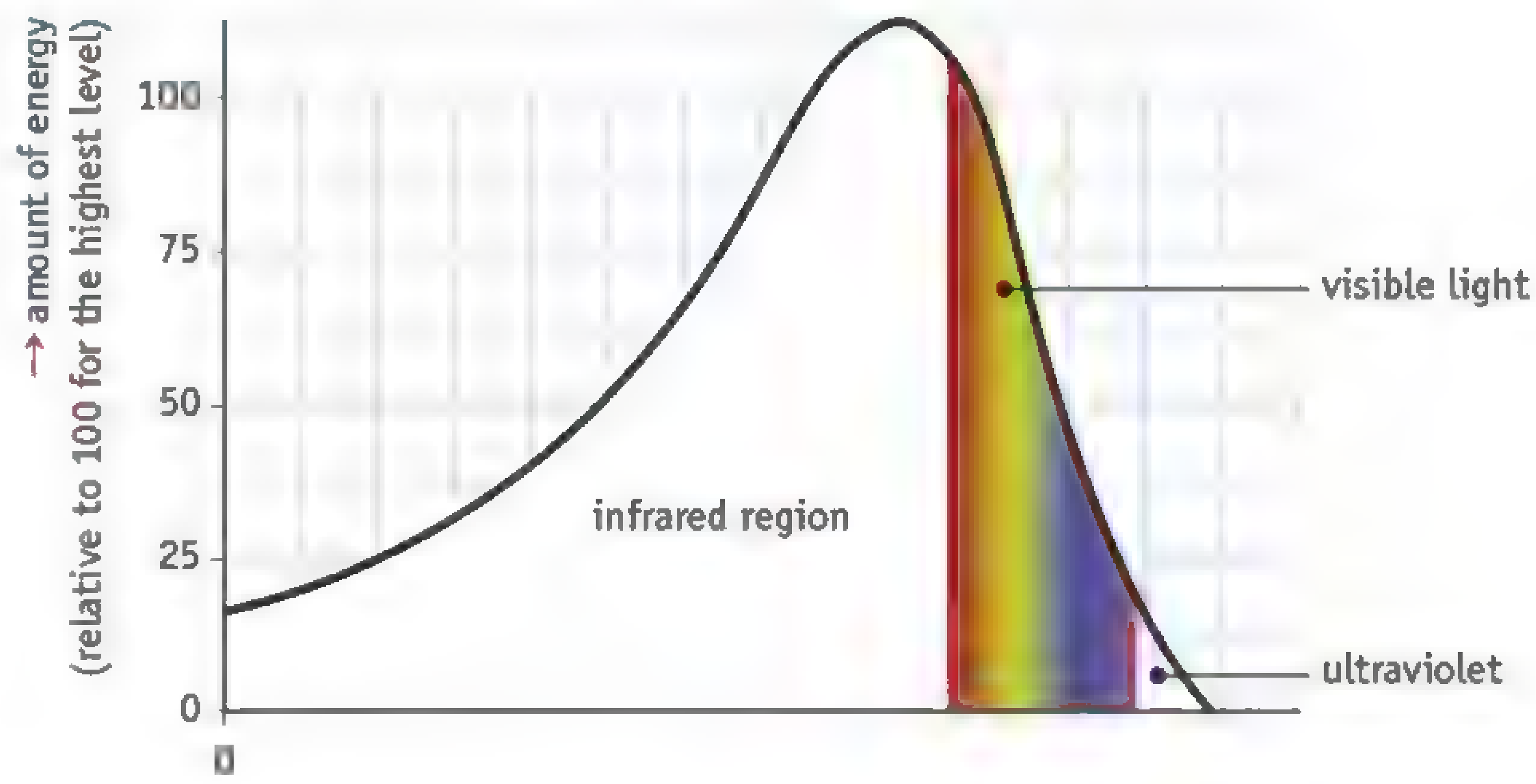


figure 9 The composition of the radiation from an incandescent light bulb.

7 Welders wear welding hoods (figure 10). The glass in these hoods absorbs infrared radiation, visible light and ultraviolet radiation.

a Suppose that the welder did not wear a hood.
Which type of radiation would then:
- be too blinding for the welder to be able to do the work?
- permanently damage the welder's eyes?
- make the welder's face very hot?

b Which type of radiation must not be completely blocked?

c What would otherwise go wrong?

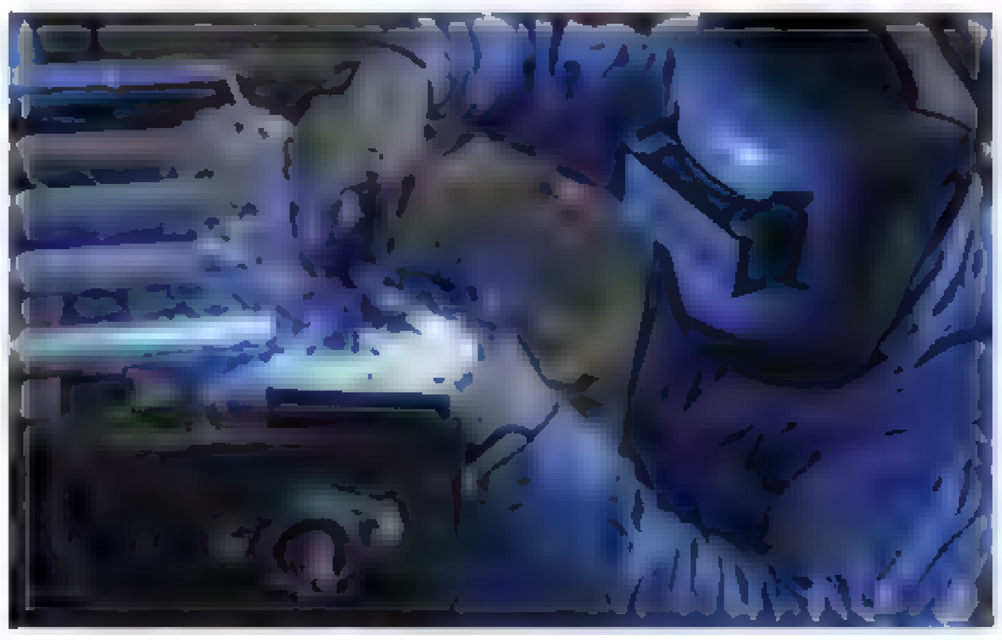


figure 10 Welder with a welding hood.

★ 8 A manufacturer of sun-tan oil has produced a rotatable disc giving times for unprotected tanning, the recommended protection factor and the maximum protected tanning time for various skin types (I, II and III). See table 1. The protection factor indicates how many times longer you can stay in the sun when the oil is used than you could if you were unprotected.
Fill the missing numbers into the table.

table 1 Tanning table.

skin type	I	II	III
unprotected tanning time (in min)	15		25
protection factor	20	12	
protected tanning time (in min)		300	200

9 Snowblindness is an inflammation of the cornea. You get this condition if your eyes are exposed to too much ultraviolet radiation.

- a Why might people doing winter sports be particularly affected by it?
- b Why is there not much risk of snow blindness in the Netherlands?
- c What could you do to protect yourself against snow blindness?

Test what you know with *Test yourself*.

EXTRA ULTRAVIOLET RADIATION

10 Answer the following questions.

- a What type of ultraviolet radiation is responsible for skin ageing?
- b What type of ultraviolet radiation is responsible for tanning the skin?
- c What type of ultraviolet radiation is needed for producing vitamin D in the body?
- d How can you protect yourself against the harmful effects of the sun's ultraviolet radiation?

11 UVC lamps are sometimes used for disinfection. That is because UVC kills 99% of bacteria and viruses in just a short time. Small self-driving vehicles with large UVC lamps on have even been made for disinfecting large spaces in just a short time.

- a Explain why it is safer to use self-driving vehicles instead of humans.
- b A chair that has been pushed under a table can sometimes not be disinfected very well this way.
  Explain why.

12 Small items can be disinfected in a disinfection cabinet (figure 11). This is a type of oven that has UVC lamps in the top.

- a Explain why the walls of the cabinet are shiny.
- b Why is there no danger from the UVC after the items have been disinfected?

figure 11 A disinfection cabinet.

Experiments

EXPERIMENT 1 MAKING A SPECTROSCOPE

20 minutes

Introduction

If a shower of rain passes over on a sunny day, you can sometimes see a rainbow. The sun is then shining through water droplets that split the sunlight up into various colours. You can also use a spectroscope to split white light up into its various component colours.

Goal

In this experiment, you are going to make a simple spectroscope yourself using a piece of diffraction foil.

Requirements

- ☐ piece of diffraction foil
- ☐ a strip of cardboard
- ☐ sticky tape
- ☐ hole punch

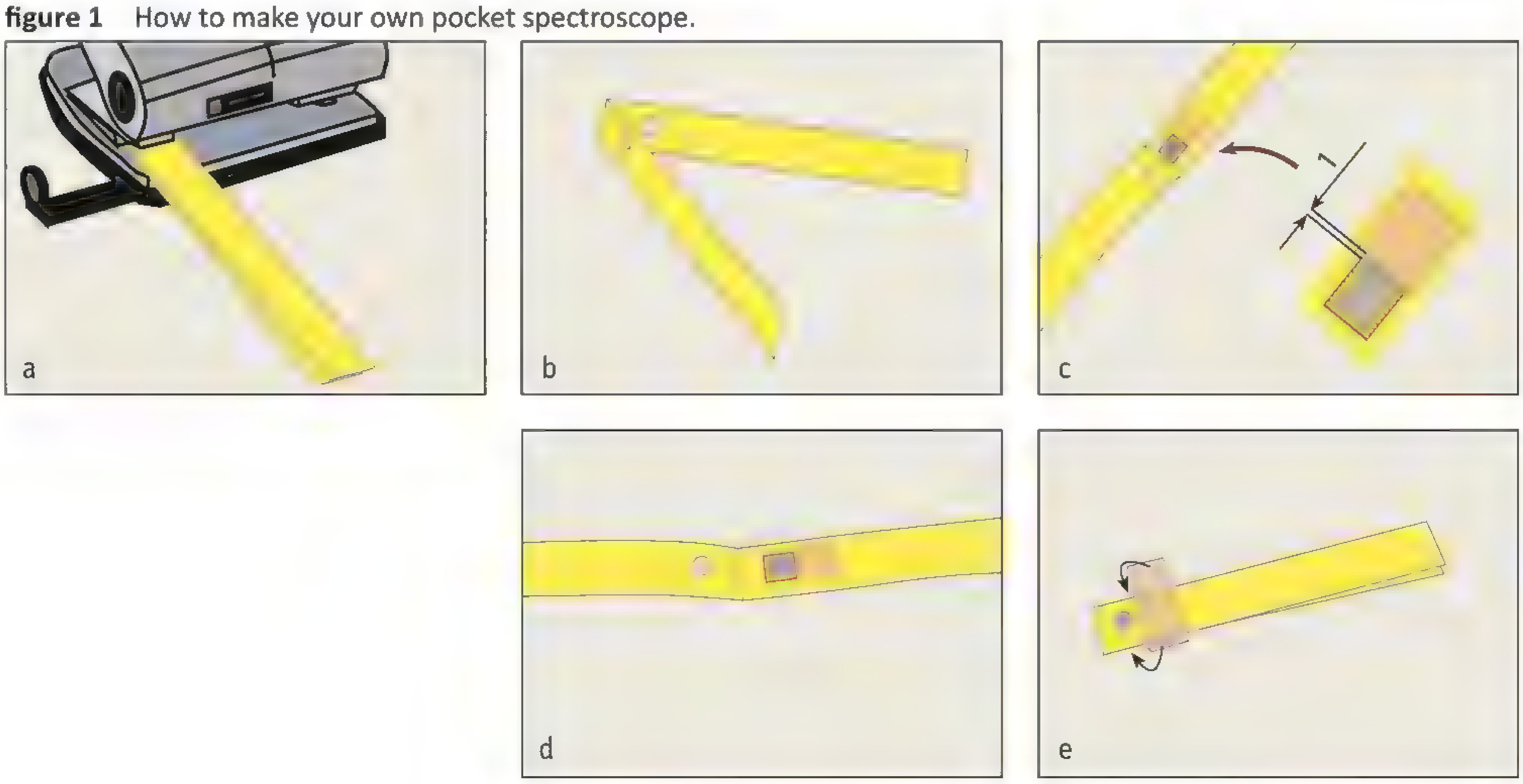
Take care! One side of the diffraction foil (the side with a slight haze) is very fragile. Do not touch this side with your fingers.

Doing the experiment and writing it up

Making a spectroscope

- Fold the strip of cardboard double (one short edge up against the other).
- Push the fold into the hole punch (figure 1a). Make a hole close to the fold (figure 1b).
- Tear off a small piece of sticky tape and stick it onto the edge of the diffraction foil (with about 1 mm overlap).
- Use the sticky tape to place the diffraction foil over the hole in the cardboard strip (figure 1c).
- Press the sticky tape firmly in place to hold the diffraction foil in position (figure 1d).
- Fold the strip double again. Use another piece of sticky tape to hold the strips together just below the perforation (figure 1e).

figure 1 How to make your own pocket spectroscope.



Using a spectroscope

- Hold the spectroscope right in front of one eye and look just next to a light source. You can then see the colours that the light source contains.
- Look outside through the spectroscope (but NOT straight in the direction of the Sun!)

1 What colours are there in daylight?

....

....

- Look through the spectroscope at various sources of white light.

2 Does the light from these sources have the same composition as sunlight? How can you see that?

....

....

....

EXPERIMENT 2 SPECTRA OF LAMPS

30 minutes

Introduction

The light from a lamp consists of different colours. If you look at the light of a lamp through a spectroscope, you see the various colours next to one another. A series of colours like this is called the spectrum of the light.

Goal

In this experiment, you are going to be investigating the spectra of various bulbs.

Requirements

- ☐ spectroscope
- ☐ fluorescent tube
- ☐ sodium lamp
- ☐ energy-saving bulb
- ☐ halogen bulb
- ☐ mercury lamp
- ☐ coloured pencils

Doing the experiment and writing it up

- Use the spectroscope to look at the spectra of the various lamps.

1 Use coloured pencils to draw the spectra of the lamps.

2 Which lamp only emits a single colour of light?

....

EXPERIMENT 3 UMBRA AND PENUMBRA

15 minutes

Introduction

Having two lamps above a table-top gives different shadows than a single lamp. You can then often see a dark 'core' shadow (umbra) between two lighter half-shadow areas (penumbra).

Goal

In this experiment, you are going to be investigating how you can produce an umbra and a penumbra.

Requirements

- ☐ retort stand with clamps
- ☐ 2 bulbs
- ☐ voltage source
- ☐ wires
- ☐ square piece of cardboard
- ☐ sheet of white paper

Doing the experiment and writing it up

- Set the experiment up as shown in figure 2.
- Hold the square of card between the bulbs and the sheet of white paper. Move the piece of card up and down.

1 Describe how you see the shadows change:
   a as you move the card upwards, towards the bulbs.

....

....

....

....

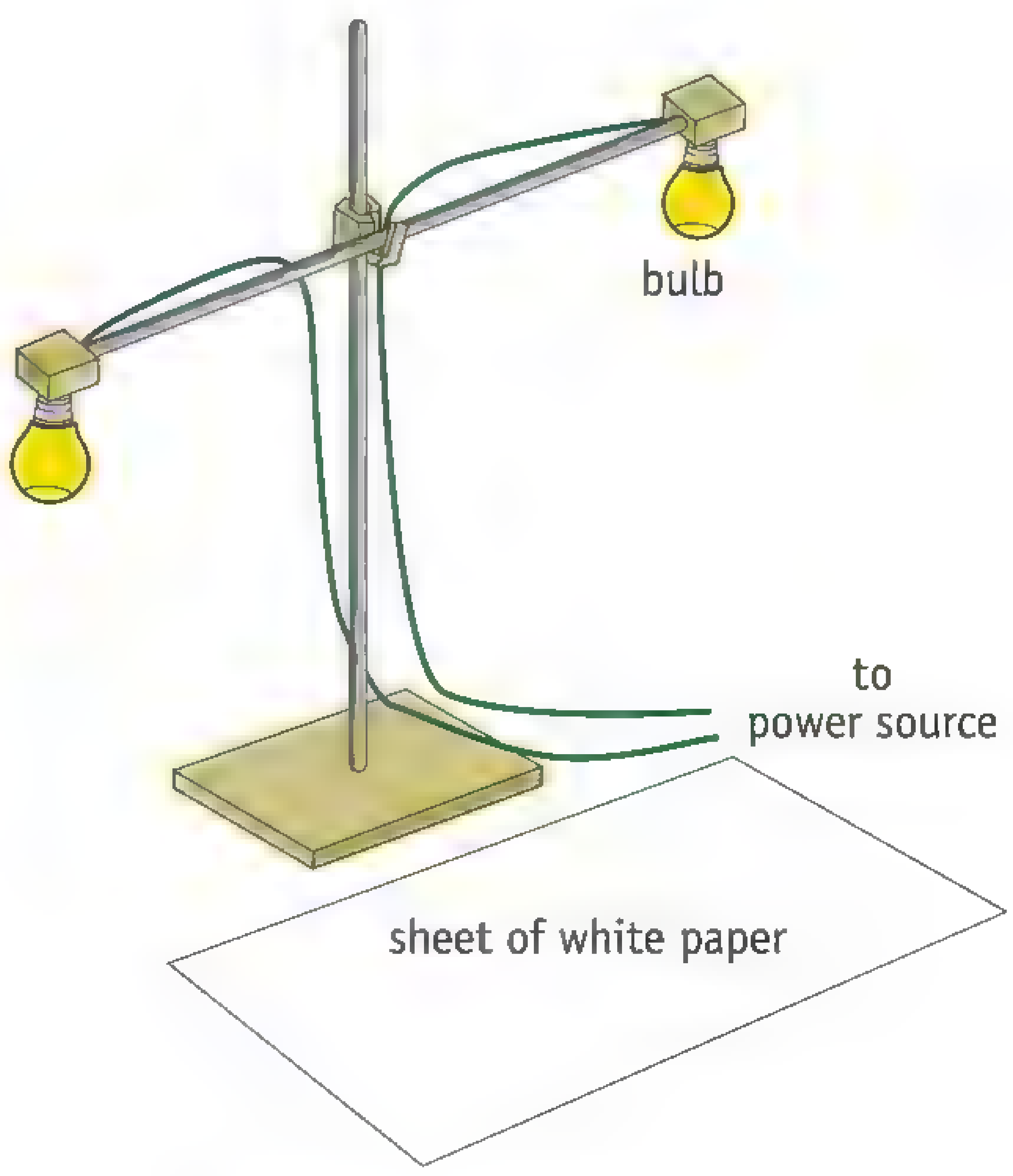


figure 2 The setup for Experiment 3.

b as you move the card downwards, towards the paper.

....

....

- Hold the piece of card so that you can see two lighter shadows next to each other, not overlapping. These are half shadows: penumbra.
- Unscrew the left-hand bulb so that it goes out.

2 Which half shadow disappears now? Why?

....

....

- Screw the left-hand bulb in again so that you have two partial shadows again. Now hold the card so that the two partial shadows start to overlap.

3 What does the umbra (the core shadow area where the two half shadows overlap) look like?

....

....

4 Sketch what these shadows look like. Write 'umbra' and 'penumbra' in at the appropriate places on your sketch.

EXPERIMENT 4 LOOKING AT MIRROR IMAGES

15 minutes

Introduction

The mirror image of an object looks just like the object itself – or so you would say at first sight. But you soon see that there is something different about the mirror image if you look at letters in a mirror. A word that you could normally read fluently suddenly looks different.

Goal

You are going to investigate the difference between mirror images and reality.

Requirements

☐ mirror

Doing the experiment and writing it up

- Look at the person next to you in the mirror.

1 Can the person next to you see you in the mirror at the same time?

....

- A sentence has been written on the board in mirror writing. Look at the board in the mirror.

2 What does the sentence look like now?

....

- Write your name while looking at your hand holding the pen in the mirror.

3 Explain what makes this so difficult.

....

....

....

- Write your name in mirror writing without using the mirror.

4 Check the result in the mirror. Did you get it right?

....

5 Have a look at figure 3. What word is written in mirror writing here?

....

figure 3 A practical application of mirror writing.

6 Explain why mirror writing has been used here.

....

....

....

- Write the words 'STOP POLICE!' in mirror writing without using the mirror.

7 Check the result in the mirror. Did you get it right?

....

8 Where might you see this phrase in mirror writing, do you think?

....

....

....

....

EXPERIMENT 5 THE LAW OF REFLECTION

15 minutes

Introduction

You can use a small mirror to reflect the light of the sun onto a wall. You then see a spot of light appear at a single place. If you move the mirror, the patch of light moves too. Do you think you could predict where the sunlight will end up?

Goal

In this experiment, you investigate the direction that a mirror reflects light in.

Requirements

- ☐ mirror
- ☐ light box
- ☐ diaphragm with a single aperture

Doing the experiment and writing it up

- Place the mirror at the position indicated in figure 4.
- Place the diaphragm with a single opening in the light box.
- Direct a ray of light at the mirror, as shown in the figure. In this case, the angle of incidence is 30°.
- Determine the angle of reflection for each angle of incidence.

1 Write the measurements down in table 1.

table 1 The measurements for Experiment 5.

angle of incidence *i*	angle of reflection *r*
10°	
20°	
30°	
40°	
50°	
60°	
70°	
80°	

2 What is your conclusion?

....

....

....

....

....

....

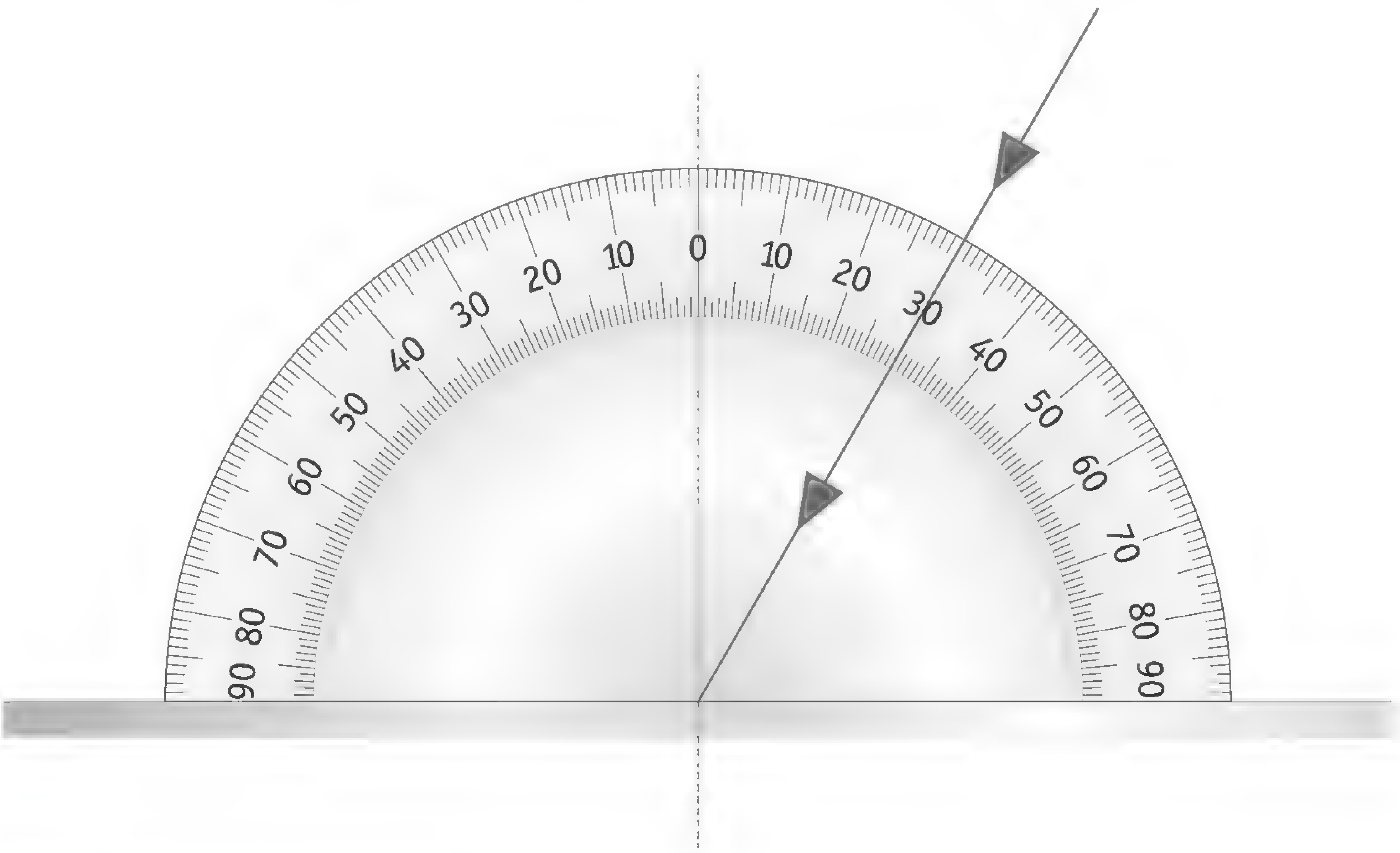


figure 4 Use this drawing for Experiment 5.

EXPERIMENT 6 THE POSITION OF THE MIRROR IMAGE

20 minutes

Introduction
The mirror image that is created by an object in front of a mirror is a virtual image (it has no real presence).

Goal
You can however investigate exactly where this virtual image is located.

Requirements
- ☐ mirror
- ☐ mirror holder

Doing the experiment and writing it up
- Place the mirror at the position indicated in figure 5, perpendicular to the paper.
- Draw a dot at the point where you see the mirror image of P_1. Write I_1 next to it.
- Do the same for points P_2, P_3 and P_4, labelling the image points I_2, I_3 and I_4 respectively.
- Join P_1 to I_1, P_2 to I_2 and so forth.

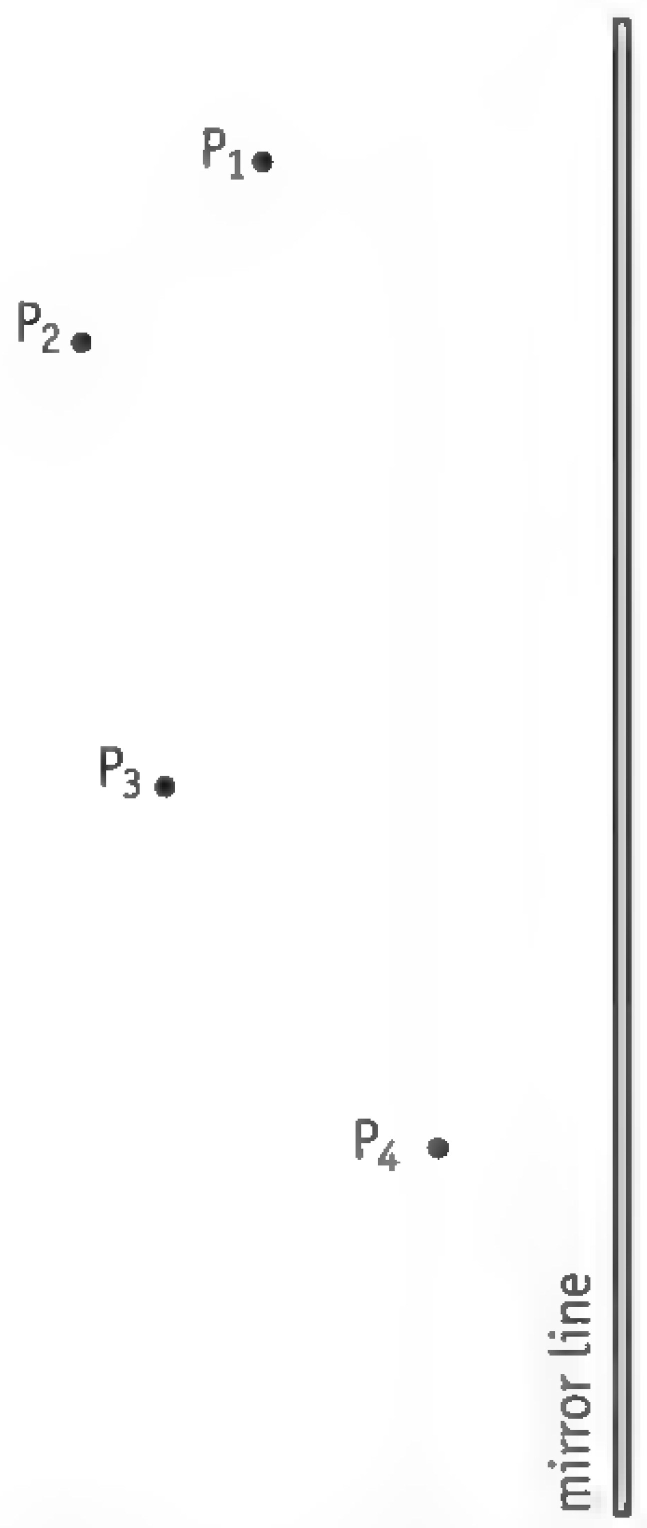


figure 5 The position of the mirror image.

1 What can you say about where the mirror image is located?

....

....

....

....

2 Have a look at figure 6. Use the mirror to help draw the mirror image of the various letters.

figure 6 A word as a mirror image.

EXPERIMENT 7 FLUORESCENCE

15 minutes

Introduction

If a UV lamp is shone onto a fluorescent material, the ultraviolet radiation is absorbed. Part of that absorbed radiation is then re-emitted as visible light: you can see the material ‘light up’. A ‘blacklight’, as they are known, can be used as a UV lamp.

Goal

You will be investigating how a blacklight works. The question you are studying is:
What do banknotes, reflective strips on raincoats and highlighter pen ink look like when illuminated with UV light?

Requirements

- ☐ blacklight
- ☐ banknotes
- ☐ safety jacket with reflecting strips
- ☐ highlighter pen
- ☐ sheet of white paper
- ☐ partially blacked out room

Doing the experiment and writing it up

- Shine the blacklight onto various banknotes.

1 Where can you see fluorescence?

....

2 Describe what the fluorescence looks like.

....

....

- Shine the blacklight onto the sheet of white paper.

3 Is there any fluorescence now?

....

4 What does the paper look like?

....

....

- Draw a simple shape on the paper using the highlighter pen and look at it under the blacklight.

5 Is there any fluorescence now?

....

6 What does the figure you have drawn look like?

....

....

- Shine the blacklight onto the jacket with the reflecting strips.

7 Is there any fluorescence?

....

8 Describe what the jacket looks like now.

....

....

EXPERIMENT 8 AN INVESTIGATION INTO A SHADOW PLAY

45 minutes

Introduction

Imagine it: in a shadow play or shadow theatre, a story is told using shadow puppets (figure 7). The audience sits in front of a translucent screen and the actors are behind it. The screen is lit from behind by a lamp. The players hold up flat puppets (on sticks) in front of the light so that the shadows of the puppets appear on the screen. By moving the puppets back and forth, the shadows on the screen can be made larger or smaller. In this exercise, you are going to be investigating what the size of the shadow image depends on.

figure 7 A shadow play.

Goal

In this experiment, you are going to work out a way of predicting the size of a shadow beforehand.

Requirements

For this experiment, you have to think up for yourself what equipment you will need.

Doing the experiment and writing it up

- Think about the ways you know for predicting the value of a variable. Which method are you going to use?
- Formulate the research question (or questions) that you want to answer in this investigation.
- Think about how you can give the most reliable answer to the research question. What are you going to measure, what items will you need for the practical, and how are you going to process the measurements?

1 Make a work plan for this study.

- The work plans will be discussed with the rest of the class in the next lesson. If necessary, you can make improvements to your own work plan after that.
- Then carry out the experiment.

2 Write down all the measurements, calculations and results in your exercise book.

- Your teacher will tell you whether or not you have to write up a report on this experiment.

Your biological clock

"I've had a problem for about the last six months. It makes no difference how early or late I go to bed. I just get really tired if I'm out of bed before eleven. Not that I can't wake up at five thirty when I need to," says 'Grandmommy' on the forum scholieren.com, "but my body just seems to need a lot of sleep." But she doesn't feel guilty about it. "Being able to sleep for twelve hours straight or more is a real teenager thing – it's because of the chemicals in your brain."

Oversleeping

Oversleeping is a topic that gets a lot of responses on the forum. "I've got that too to some extent," writes 'Paranoid'. "I've tried all sorts of things to get me into a good rhythm. I got up and went to bed at about the same time for a while. The net result was that I lay awake in bed for hours, not allowing myself to get up. I tried some homeopathic rubbish, but it had no effect. I even took heavy sleeping pills for a while, but they gave me hallucinations. No luck."

An anonymous school student replied with some tips. "I know what it's like and it's unpleasant. Compared to winter, I don't oversleep so easily in the summer because it's light then. So in the winter I put my desk lamp (bright and nasty) on a timer and point it at my bed. I also set several alarms and force myself to get out of bed and splash cold water over my head when I wake up. That generally helps."

Not lazy – just a teenager

Why do so many schoolchildren have difficulty getting up in the morning? When you finish primary school, you often have to travel further to secondary school, which sometimes starts earlier too. But that's not the only difference. Researchers have discovered that you really do sleep longer after primary school. All kinds of other processes in your body then shift to a later time as well. So wanting a lie-in does largely have a biological cause.

'Grandmommy' noted on the forum that wanting to lie in is related to chemicals in your brain. One substance that plays a key role in sleep is melatonin. This compound is made and broken down by your body in a kind of day-and-night pattern. Normally the level increases in the evenings and falls again in the mornings. When it gets dark, melatonin levels increase and you get sleepy. Light can shift or disrupt this melatonin rhythm.

Biological clock
Almost all organisms on Earth have a built-in diurnal rhythm, the biological clock (figure 1). This lets you cope properly with the daily changes in your surroundings such as light and dark or higher and lower temperatures. So the biological clock affects processes in your body, including your behaviour.

figure 1 Biological clock.

The biological clock is located in a small region in the brain consisting of just 20,000 nerve cells. Together, those cells product a rhythm that repeats on a cycle of about 24 hours. The diurnal change from light to dark then ensures that the biological clock is kept roughly in step every day.

In the past, before there was electric lighting, it really got dark at night. Nowadays it is easy to turn a light on anywhere. And you watch screens that give off light more and more often, such as your smartphone, tablet, laptop or TV. This light can disrupt the rhythm of your biological clock, which affects your sleep pattern. If you don't sleep enough, your memory is poorer and you are less alert. If you sleep badly for a long period, there is even a chance that it will make you aggressive or depressed.

Better grades
In 2014, two pupils at a secondary school in Hardenberg did a study (together with Groningen

SCREEN COLOURS
A TV or computer screen is made up of light-emitting strips, dots or squares that are called subpixels. Whatever their shape may be, the subpixels almost always have the same three colours: red, green and blue. You can see that if you look at a screen using a strong magnifying glass (figure 2). From a normal viewing distance, the individual subpixels all merge together to give a single picture in all kinds of colours.

Each subpixel can be switched on and off individually. In a part of the image that is red, only the red subpixels will be emitting light; in a green part of the image it will only be the green subpixels, and so forth. Other colours are made by mixing red, green and blue light. Yellow, for example, is produced by making the red and green subpixels light up together. Green and red light mixed together give the same impression as pure yellow light.

The reason why red and green together make yellow has to do with the way your eyes work. There are three different types of cones (light-sensitive cells) in the retina, each with its own colour sensitivity. One type responds to red, orange and yellow light; another to yellow, green and blue-green light; and the third responds to blue-green, blue and violet light. A mixture of red and green light gets a response from the first two types of cones, in exactly the same way as pure yellow light does, and we therefore perceive it as yellow.

University) for their graded paper into sleep deprivation in adolescents. They looked at the relationship between the sleeping patterns and the school results of 700 fellow pupils at the school. In particular, older teenagers with a 'late' biological clock (figure 2) scored half a grade lower on average in tests than pupils whose biological clock ran 'early'. When the 'late' pupils took tests that were held later in the day, they did quite a bit better. After this study, the secondary school shifted the start of lessons from eight o'clock to eight thirty or nine. According to one teacher, the pupils were happier with that and more alert, so they got better grades.

"When children are about fourteen, their pattern of sleeping and waking shifts and so does their biological clock. They want to stay in bed a lot longer."

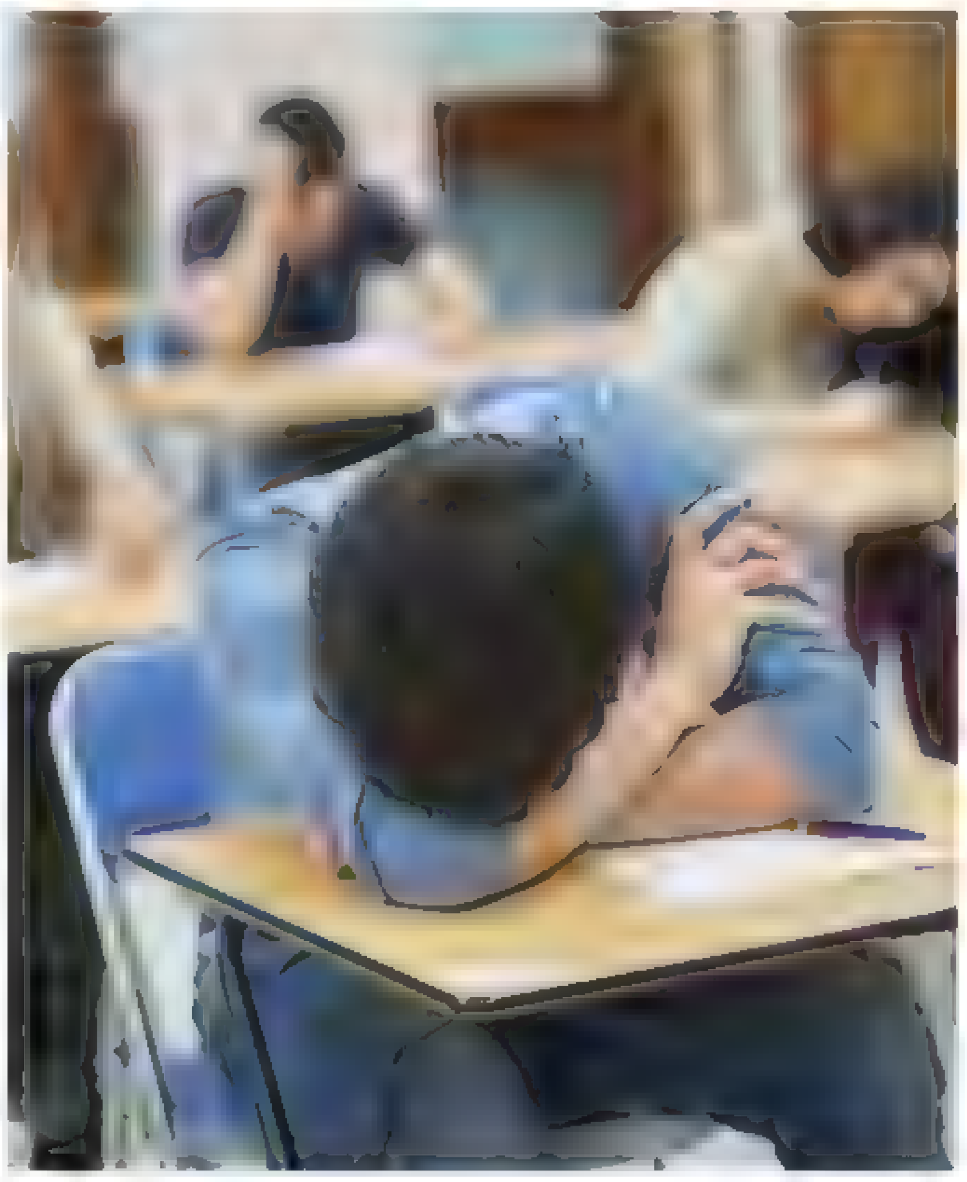


figure 2 A pupil whose biological clock runs 'late' during an early-morning test.

Blue light means action

So light affects your biological clock. The greatest effect comes from blue light. When the sky is blue, the weather is usually sunny and that is reflected in many people's humour. You often feel less sleepy on a sunny day than during a grey day too. The spectrum of light that is emitted by the LED screen of your phone or gaming console, for instance, contains a lot of blue. This blue light sends a signal to your brain that you have to stay awake, even if it's the evening. Everyone is sensitive to blue light in the evening, but the effect seems to be much greater for young people aged fifteen to seventeen.

Melatonin concentrations increase by less, or can even decrease if you are busy doing things with a LED screen in the two hours before you go to sleep. On top of that, if you're enjoying apps or games in the evening, that activity will affect the moment that you start feeling sleepy. It's easy to forget the time and you'll go to sleep later. But the alarm clock still goes off at the same time the next morning. In the end, it means you get less sleep.

Light for waking up by

The tip that the anonymous pupil gave on the forum is by no means weird: being woken up by a bright light on a timer switch, pointed at your bed. You can use light in the morning to help shift your biological clock to an earlier phase. Then you'll be more awake for that exam early in the morning! Researchers have discovered that you wake up more quickly in the morning if you've been in reasonably bright white or blue light for 30 to 60 minutes. An alarm clock light (figure 3) is based on the same principle. The brightness of this lamp increases slowly from half an hour before the alarm goes off, just like the sun coming up. Although your eyes are still closed at that point, you wake up more easily and you feel better the whole day long.

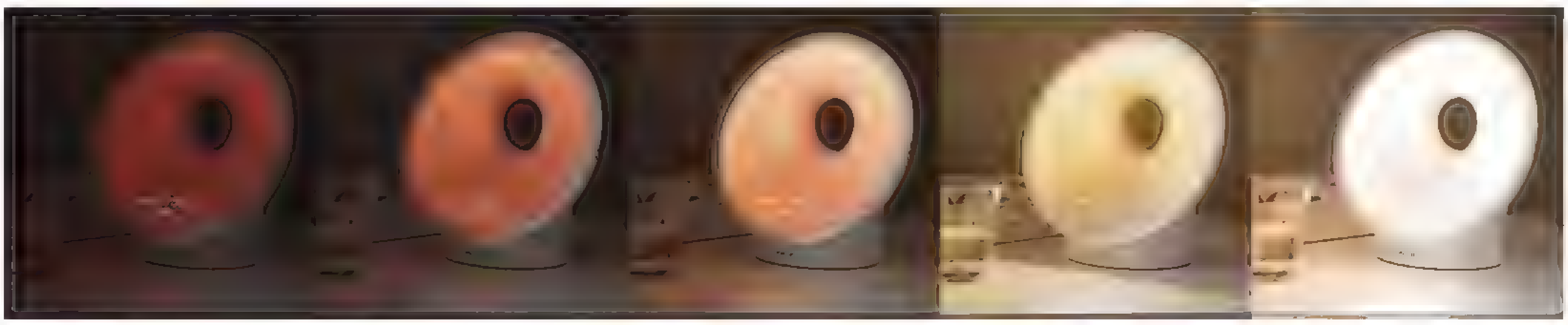


figure 3 An alarm clock light.

EXERCISES

1 Figure 3 shows you an alarm clock light that helps you wake up. There are also alarm clock lights that have a function that help you go to sleep more easily.

a What features will the light that helps you get to sleep have?

b Would using the light from a smartphone help you to fall asleep?

c Would using the light from a smartphone help you to wake up more quickly?

2 Almost all organisms have a diurnal rhythm.

a Write down three animals that do not have a day-and-night rhythm.

b Write down three animals that have an inverted day-and-night pattern.

c Animals that have a nocturnal rather than diurnal rhythm also produce more melatonin in the evenings.
What general conclusion can you draw from this for animals?

○ A Melatonin keeps animals awake.
○ B Melatonin controls animals' biological clocks.
○ C Melatonin makes animals sleepy.

3 The two secondary school pupils from Hardenberg who did their graded paper about sleep and school grades were Amy Pieper and Anne Siersema. You can download the graded paper from https://www.knawonderwijsprijs.nl/winnaars/winnaars-2014/de-invloed-van-chronotype-en-tijdstip-van-de-dag-op-schoolprestaties.

a Amy and Anne refer to different 'chronotypes'.
Which chronotype are you?

b Amy and Anne give recommendations for schools (page 15).
Write down one benefit and one disadvantage of starting school later.

c Amy and Anne also give recommendations for pupils (page 16).
Write down two things that might let you do better at school.

Course material overview

6.1 LIGHT AND COLOUR

REMEMBER

- An object the produces light is called a light source. The sun and the stars are natural light sources. Candles, LED bulbs and fluorescent tubes are artificial light sources that have been made by humans.
- White light consists of all the colours of the rainbow: red, orange, yellow, green, blue and violet. You can see them if you let sunlight fall onto a prism. A sequence of colours like this is called a spectrum.
- A spectroscope lets you investigate the composition of light from a source. When you look through a spectroscope, you see a spectrum of the light from the bulb (for example).
- Most of the objects around you do not emit light themselves. You can only see them when they are illuminated. The light that falls on the object is then reflected diffusely. You see the object when part of that reflected light reaches your eyes.
- A yellow jumper reflects yellow light in particular, a red jumper reflects mostly red light, a blue jumper largely blue light, and so forth. The light that is not reflected is absorbed and converted into heat.
- White objects reflect almost all the light falling on them. Black objects reflect very little light. Almost all the sunlight is absorbed.
- If you look at a purple jumper under yellow light it will look black. This is because the purple jumper mostly reflects violet light. The yellow light of a sodium lamp (for instance) is absorbed almost completely. The jumper is therefore reflecting almost no light and it looks black.

CONCEPTS

absorption
Taking up; the light that is not reflected is absorbed.

artificial light source
Object that does not produce its own light and has been made by humans, such as candles, LED bulbs and fluorescent tubes.

diffuse reflection
The light is reflected back by an object in all directions.

natural light source
Object or phenomenon that gives off light but was nor created by humans.

pocket spectroscope
Instrument for studying light. You can use it to see what colours a light source is made up of.

prism
Transparent, triangular piece of glass or plastic.

spectral colours
The pure colours in the spectrum of light.

spectrum
A sequence of successive colours made visible for example when light passes through a prism.

6.2 DIRECT, INDIRECT AND DIFFUSE

REMEMBER

- You can draw rays of light as straight lines (with an arrow in) because light moves in straight lines.
- The rays from a light source diverge as they get further from a light source, showing that the light is weaker.
- If an object blocks the light from the light source, it casts a shadow. This is a region that the light cannot get to directly.
- You can draw in the shadow of an object as follows:
  - Draw in the rays that are not quite blocked by the object. These are called the edge rays.
  - Colour in the area behind the object that is between the two edge rays. This is the area that the light cannot reach directly: the shadow.
- When an object is lit by two light sources, two shadows are cast. The shadow is darkest in the areas where the two shadowed areas overlap. This is called the umbra. To the left and right of the umbra, you can see the lighter penumbra.
- Letting the light reflect off a wall makes the wall an indirect light source.
- Diffuse light gives softer lighting and less hard-edged shadows. Diffuse light is produced by scattering.

CONCEPTS

direct light
Light that goes straight from the light source to the object.

edge ray
Ray of light that is just not quite blocked by an object.

indirect light
Light that reaches the object by reflection rather than directly.

indirect light source
Surface that reflects the light from a light source.

penumbra
Shadow area that only a small amount of the light can reach.

ray
A straight line that light moves along.

shadow
A region that the light cannot get to directly.

umbra
Shadow area that no light at all can reach.

6.3 MIRROR IMAGES

REMEMBER

- In a mirror, you see a true-to-life image of your own world: the mirror image.
- You can draw a line at the point where a ray hits a mirror, at right angles to the mirror: this is called the normal. The angle between the incoming ray and the normal is called the angle of incidence. The angle between the reflected ray and the normal is called the angle of reflection.
- In reflection by a planar mirror, the rule is always: angle of incidence = angle of reflection. This rule is known as the law of reflection.
- You can use the law of reflection to draw how a ray is reflected by the mirror.
  - Draw in the normal. The normal is always perpendicular to the mirror.
  - Determine the angle of incidence.
  - Mark in the angle of reflection.
  - Draw in the reflected ray.
- You can find the mirror image as follows:
  - Select a random point P on the object.
  - Place your protractor perpendicular to the mirror with the baseline going through point P and the zero on the mirror.
  - Draw in an image point I that is just as far behind the mirror as P is in front of it.
- Drawing in the reflected ray can also be done without using the law of reflection as follows:
  - First draw the image point for P; this is point I.
  - Find the line that goes from point I to where the ray from P hits the mirror.
  - Draw in the line, first as a dashed line behind the mirror and then as a solid line in front of the mirror.
  - The solid part in front of the mirror is the reflected ray.

CONCEPTS

angle of incidence
Angle between the incoming ray and the normal.

angle of reflection
Angle between the reflected ray and the normal.

law of reflection
A rule stating that the angle of incidence equals the angle of reflection.

mirror
Sheet of glass onto which a thin layer of aluminium or silver has been applied.

mirror image
Virtual image that you see in a mirror.

mirror reflection
Light bounces off in a specific direction and not in all directions as it does in diffuse reflection.

normal
Construction line that is perpendicular (at right angles) to the mirror.

6.4 INFRARED AND ULTRAVIOLET RADIATION

REMEMBER

- All the objects around you – including humans and animals – emit infrared (IR) radiation. Heat lamps give off a little bit of red light that you can see, but primarily a lot of infrared.
- The spectrum of a heat lamp has the infrared radiation next to the red.
- Infrared radiation is applied in various ways:
  - in the remote control of a TV;
  - in outdoor lighting that reacts to people passing by;
  - in alarm systems and in shop doors that open and close automatically;
  - in night vision goggles that convert invisible infrared radiation into visible light.
- The sun emits ultraviolet (UV) radiation as well as light. When you sunbathe, your skin receives that radiation. Your skin responds to that by producing additional pigment: you get a tan.
- You have to be careful not to get too much ultraviolet radiation on your skin or you may get sunburnt. Too much ultraviolet increases the risk of skin cancer.
- There are also lamps that primarily emit ultraviolet, such as the UV lamps in a solarium or blacklights in discos.
- The spectrum of a UV lamp has the ultraviolet radiation next to the violet.
- The presence of UV radiation can be demonstrated with a fluorescent substance. That means a substance that emits visible light when UV radiation falls on it.

CONCEPTS

fluoresce
To emit visible light when UV radiation falls on something.

heat lamp
Bulb that primarily emits infrared radiation.

infrared radiation
Invisible radiation that you can feel as heat.

ultraviolet radiation
Invisible and harmful radiation that is present in sunlight.

UV lamp
Bulb that primarily emits ultraviolet radiation.

Go to the *Flash cards* and the *Diagnostic test*.

7

The universe

THE EARTH AND THE UNIVERSE

The Earth is a modest little planet in a quiet corner of the universe. There are other places where a lot more is going on, such as this area in the constellation Orion. Astronomers do a lot of research into regions like these to get a better understanding of the processes in the universe.

1 Stars, sun and moon

LEARNING OBJECTIVES

7.1.1 You can describe how the stars appear to move in the sky (as seen from Earth).
7.1.2 You can explain what causes the apparent motions of the stars.
7.1.3 You can describe how the Sun moves through the constellations of the zodiac.
7.1.4 You can explain what it meant by the terms Earth's axis, celestial pole and plane of the ecliptic.
7.1.5 You can explain what causes the seasons and the variation of day length.
7.1.6 You can explain the phases of the Moon and how the occur.
EXTRA 7.1.7 You can use drawings to explain how a solar eclipse occurs.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES						
	7.1.1	7.1.2	7.1.3	7.1.4	7.1.5	7.1.6	7.1.7
Remembering			1a, 2c	1bc, 3b	1d	1e, 2ef	
Understanding		2a	2b, 5bcd	5a	2d, 7cd	9abcde	12a
Using	3a			4abcd	7ab		10, 12bc
Analysing	3c	6abcd			7e, 8ab		11, 12d

People have been following the courses of the sun, moon and stars through the heavens for thousands of years. The Earth was the fixed point of reference in all that for a long time: all the movements were described as you see them from the Earth. That picture of the universe only changed during the last five hundred years.

THE STARS

To see the stars clearly, you have to go somewhere that is properly dark at night. That can be difficult in the Netherlands because there is too much light from other sources. Places that are deserted, a long way from major population centres, are better. On a clear and moonless night, you can then see more than two thousand stars in the sky.

If you look at the stars regularly, you will soon recognize various patterns. Groups of stars form recognizable patterns that always have the same size and shape. These patterns are called constellations. A well-known example is the hunter Orion (figure 1). Astronomers use a list of 88 constellations, each with its own name, for orientation among the stars.

figure 1 The constellation of Orion can be recognized by the three stars that make up his belt.

If you keep an eye on a star for a while, you will notice that it moves across the sky. Stars are continually rising in the east, moving upwards at an angle in a big curve to the south. They reach their highest point there and then set again, until you see them disappear below the horizon in the west.

Stars that rise in the northeast stay above the horizon for a long time. They reach their highest point almost directly above your head. And to the north, there are stars that do not set at all. They move in big circles around a central point, high up in the sky. That point is called the **north celestial pole**. There is a bright star there that is called Polaris or the Pole Star.

Astronomers thought for a long time that the Earth was stationary and the stars moved around it. Which is indeed the way it appears, viewed from the Earth. After about 1500, they realized that the stars were actually stationary. They only seem to move because the Earth is rotating around its own axis; the **Earth's axis** is an imaginary line running through the Earth, pointing at the Pole Star. This movement is called the Earth's **axial rotation** (figure 2).

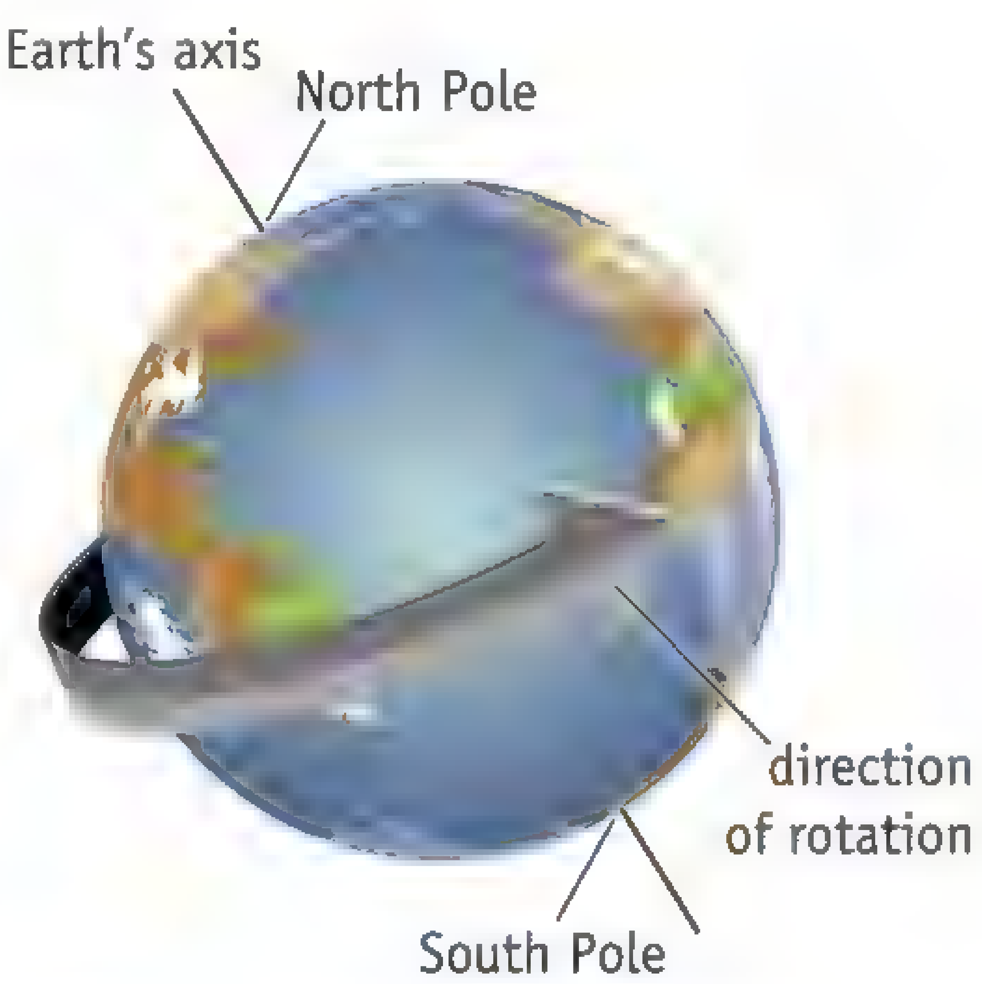


figure 2 The Earth's axial rotation.

THE SUN

Just like the stars, the sun traces out a large arc from the east via the south to the west. But even in ancient times, they discovered that the sun lags a little bit more behind the stars every day. The stars are at the same place in the sky again 23 hours and 56 minutes later. The sun takes 4 minutes longer. The result is that the sun moves a little bit each time with respect to the stars in the sky.

In spring, the sun moves successively through the constellations of Pisces, Aries and Taurus.

- In mid-March, the sun rises at the same time as the constellation of Pisces. You can't see that constellation then because the light from the rising sun makes all the stars invisible. But astronomers could tell from the positions of the other constellations that Pisces and the sun were at the same place in the sky.
- By the end of April, the situation has changed. The sun will be then by clearly behind the constellation of Pisces, which can then already be seen in the east before the sun comes up. The sun is now rising together with the constellation of Aries.
- By the end of May, Aries has also caught and passed the sun. That constellation is then also rising above the eastern horizon before the sun comes up. The sun is now rising together with the constellation of Taurus.

And so it goes on throughout the year. The sun is in front of a different constellation for about a month. Many of the constellations in question have animal names (figure 3). That is why the strip of sky containing these constellations is called the **zodiac** (from the Ancient Greek for "little animals"). After a year, the sun has moved through all the signs of the zodiac and is back where it started.

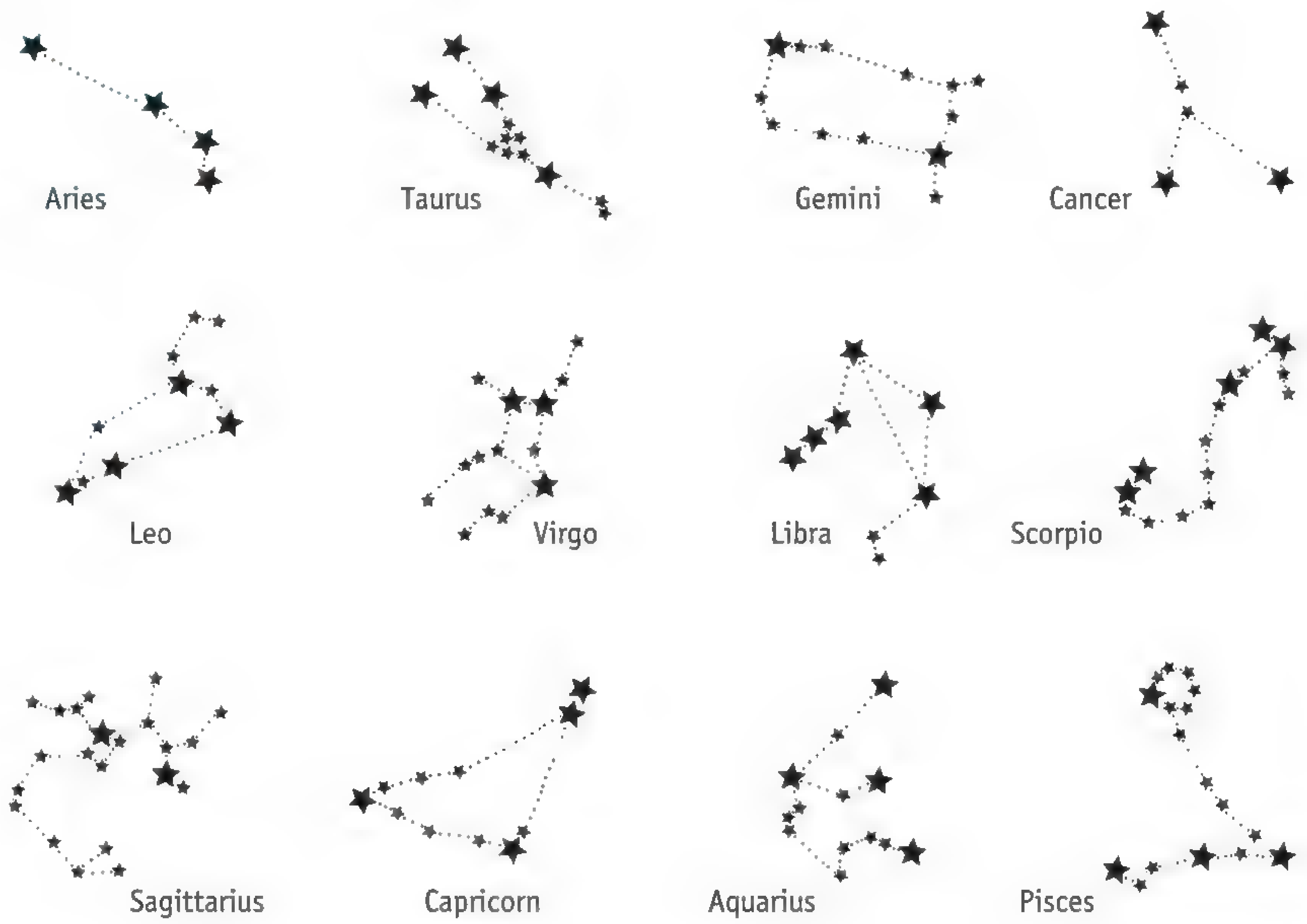


figure 3 The constellations of the zodiac.

Before 1500, astronomers thought that the sun went round the Earth, just like the stars did. After that, they became convinced that it is the Earth that goes round the sun. Seen from the Earth, that means that the sun is in front of different stars in the heavens. After one year, the Earth has completed a full orbit and the sun is in the same place in the heavens again.

THE TILT OF THE EARTH'S AXIS

EXP 1

The words 'horizontal' and 'vertical' have a clear meaning on the Earth, as do the words 'above' and 'below'. Things are different in space. There is no 'up' and no 'down' there: all directions are equivalent. So you need to think up an appropriate way of orienting yourself in space.

Figure 4 shows one way of indicating positions and directions in space. The orientation is then with respect to the plane containing the Earth's orbit. This is known as the **plane of the ecliptic**. Other heavenly bodies can be 'above' or 'below' that plane. That has nothing to do with the normal concept of 'above' and 'below', though: the picture in figure 4 could equally well have been drawn the other way up.

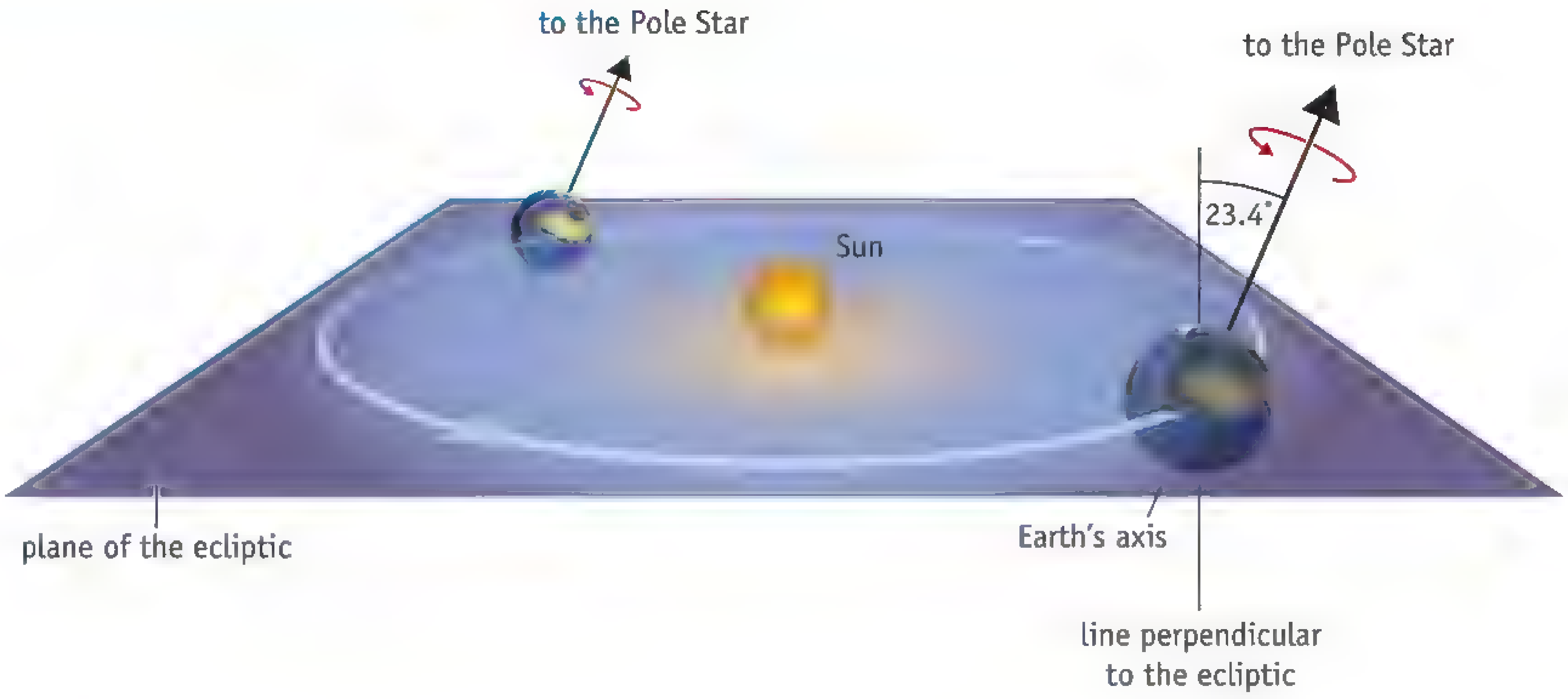


figure 4 The sun, the Earth and the plane of the ecliptic (not to scale).

As you can see in figure 4, the Earth's axis is not perpendicular to the ecliptic. The difference is a little more than 23°. That tilt means that the northern hemisphere is sometimes tilted more towards the sun, and at other times the southern hemisphere is. When the northern hemisphere is getting more sun, it is summer there; it is then winter in the southern hemisphere. Six months later, the situation has been precisely reversed.

The North Pole points most towards the sun on 21 June. Figure 5 shows you how sunlight falls on the Earth on that day. Most of the northern hemisphere is then in the light. This is the date when the day is longest and the night is shortest.

Six months later, on 21 December, the Earth is on the opposite side of the sun. The North Pole is then pointing furthest from the Sun. That means that the northern hemisphere is then largely in the dark (figure 6). That is the date when the night is longest and the day is shortest.

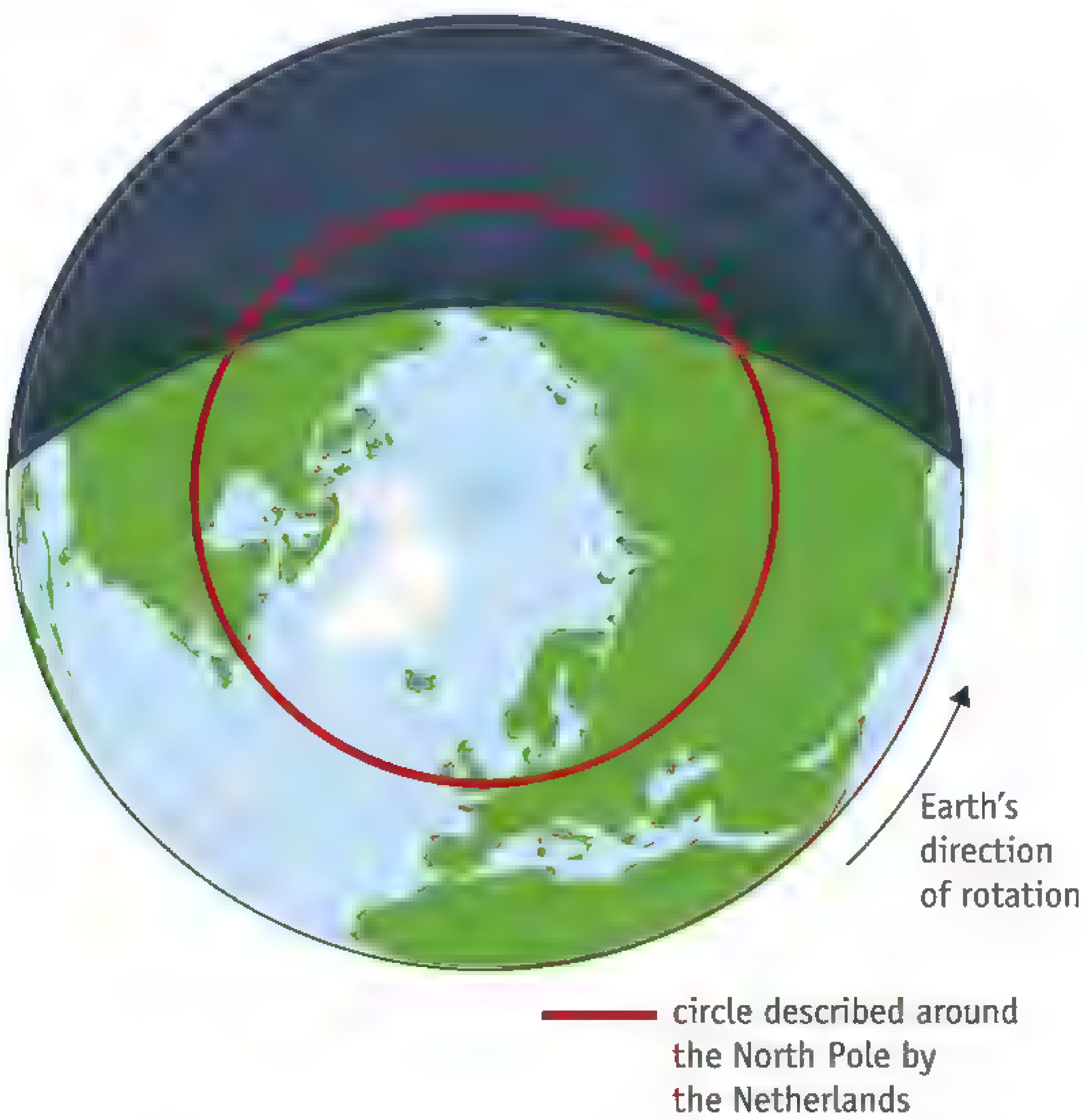


figure 5 The Earth viewed from above the North Pole on 21 June.

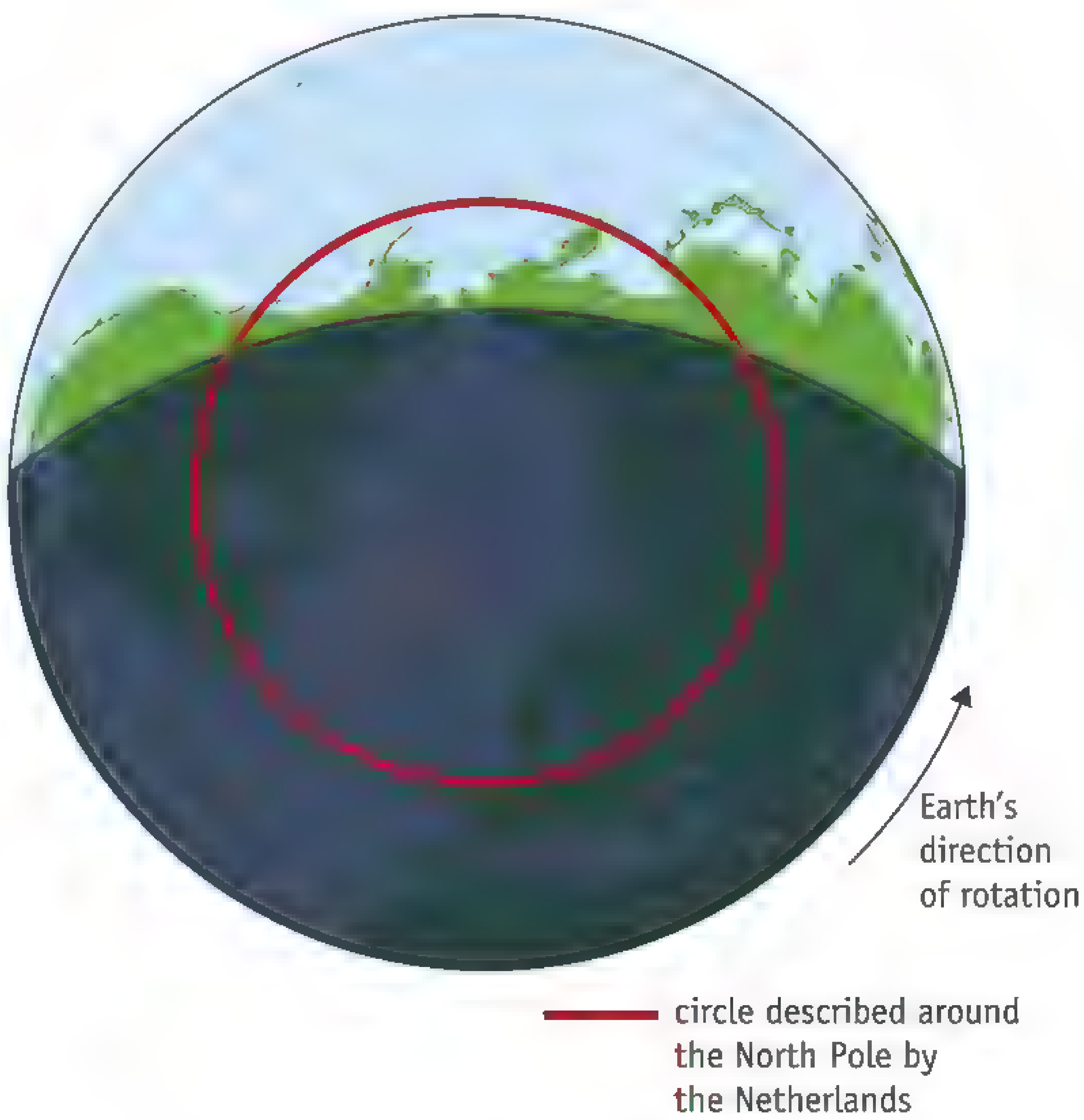


figure 6 The Earth viewed from above the North Pole on 21 December.

THE MOON

After the sun, the moon is the next most obvious heavenly body. Unlike the sun and the stars, the moon does not give off its own light. You can see the moon because it is lit by the sun. The moon and the sun seem to be much the same size when viewed from the Earth. That is because the moon is much closer to the Earth than the sun is. In reality, the sun is many times bigger.

The moon goes around the Earth in an orbit, just like the Earth goes around the sun (figure 7). About once every 29 days, the moon is roughly between the Earth and the sun. That means that the dark side is facing the Earth and you can't see the moon then. That is called a **new moon.** A little over 14 days later, the moon is on the other side of the Earth. You will then be looking at the illuminated half: that is when it is a **full moon.**

After every new moon, the moon grows (or "waxes") over the course of 14 days from a narrow fingernail to a round disc. Then it shrinks again (or "wanes") until it is another new moon 29 days later in total. The various shapes that the moon can take are called its **phases.** The phases during the waning moon are the reverse mirror image of the phases of the waxing moon.

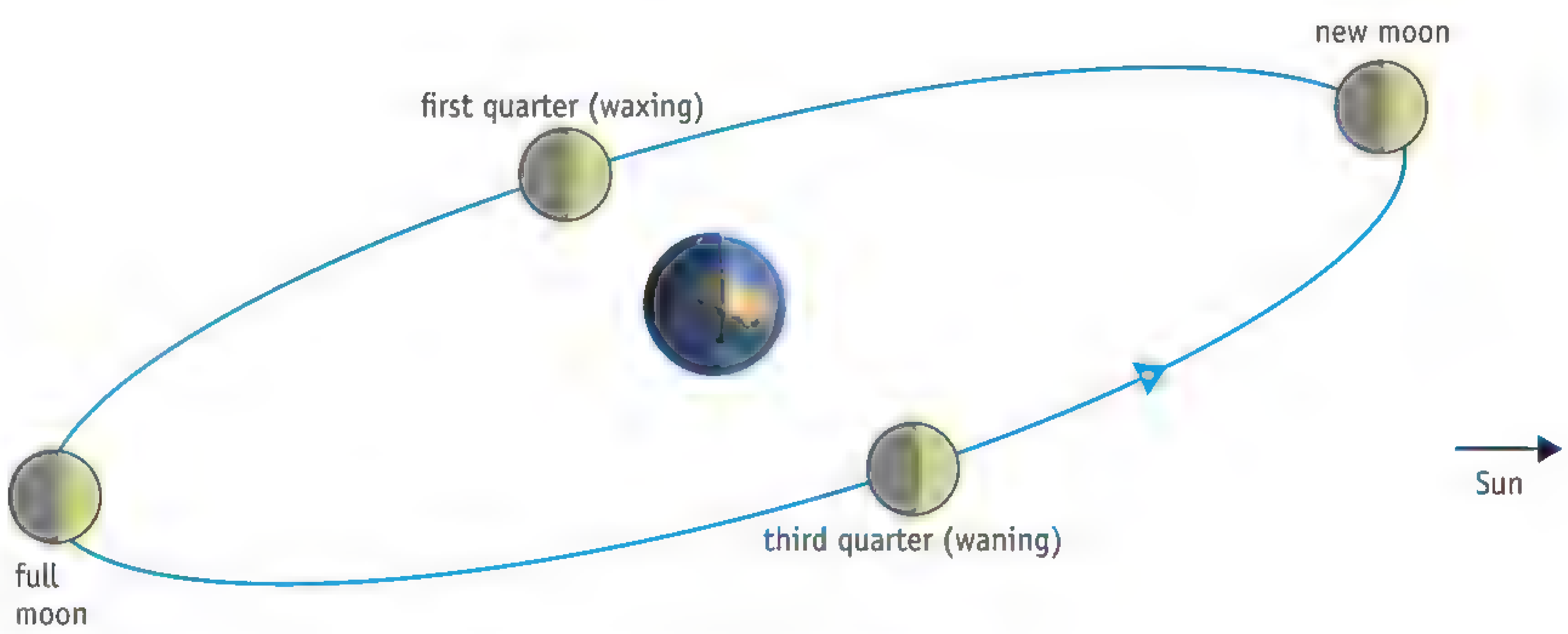


figure 7 This is how the moon orbits the Earth (not to scale).

Practice the concepts using the *Flash cards.*

EXTRA SOLAR ECLIPSES

A solar eclipse occurs when the moon (as seen from the Earth) moves in front of the sun. It starts with the moon taking a bite out of the disc of the sun. The first bite slowly increases to become a larger chunk. Finally, the moon is right in front of the sun. The eclipse is then total (figure 8). It then becomes dark all around you and you can see the stars in the sky.

figure 8 A solar eclipse; the dark disc is the moon.

In a solar eclipse, the Earth moves through the moon's cone-shaped shadow. A small part of the Earth's surface can then be in the moon's umbra. That is when a full solar eclipse can be seen (figure 9). People in the area around that are in the moon's penumbra and they see a partial eclipse of the sun.

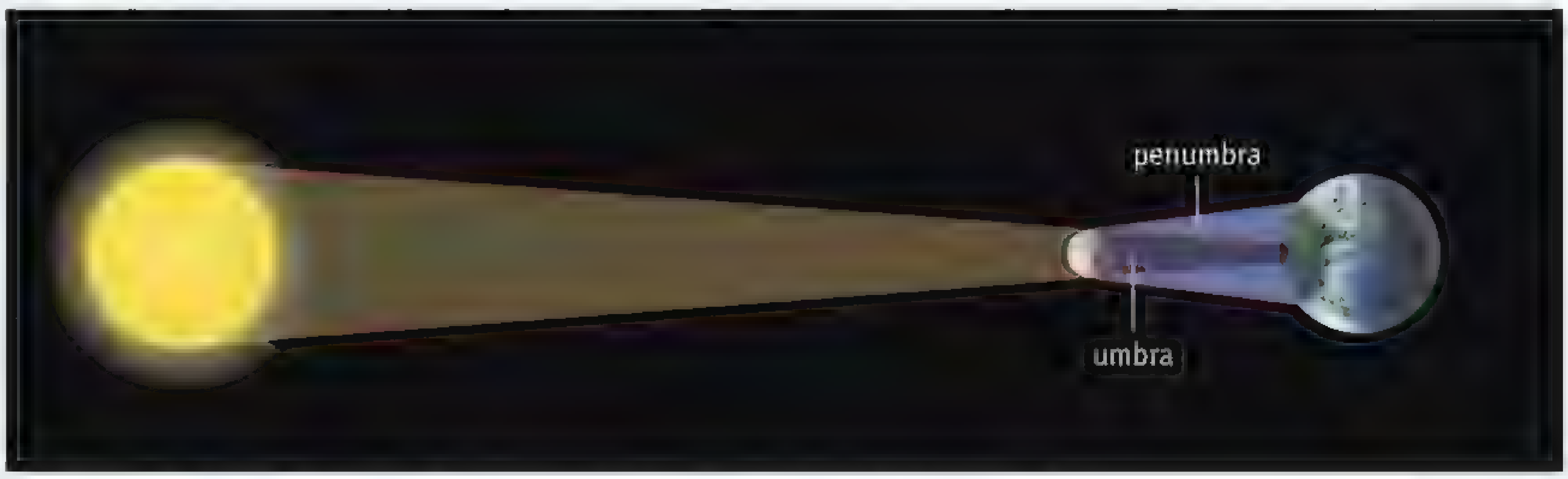


figure 9 The sun, Earth and moon during a solar eclipse (not to scale).

The moon does not block the sun during every new moon because the moon's orbit is not in the plane of the ecliptic. Instead, it is at an angle to it (of 5.1°). During one half of its orbit, the moon is above the ecliptic and during the other half it is below it. That means that the moon (as seen from the Earth) usually passes just above or just below the sun at the new moon. A solar eclipse only happens when the moon crosses the plane of the ecliptic at the new moon.

Practice the concepts using the *Flash cards*.

Unless the exercise clearly states otherwise, the exercises in this section assume that you are looking at the stars from somewhere in the Netherlands.

COURSE MATERIAL

1 Complete.

a A .... is a group of stars that create a recognizable pattern and that has given its own ....

b The .... or .... is a bright star that is high in the sky, in line with the Earth's axis when extended to the ....

c The .... is at an angle of a little over 23° to a perpendicular to the plane of the .... (= the plane of the Earth's orbit).

d When the Earth's .... is pointed towards the sun, it is summer in the northern .... and winter in the south.

e When it is a .... moon, you are looking at the dark half of the moon; when it is a .... moon, you can see all of the illuminated half.

2 Say whether each of the statements is true or false.

a To the north, you can see stars in the sky that never set. *true / false*

b The sun moves just a little further across the sky every day than the stars do. *true / false*

c Ursa Major (the Great Bear, also known as the Big Dipper or the Plough) is one of the twelve constellations of the zodiac. *true / false*

d 21 December is the longest day of the year in the southern hemisphere. *true / false*

e The moon is only visible because it is lit by the sun. *true / false*

f The sun and the moon are much the same size. *true / false*

IN PRACTICE

3 Figure 10 shows you a time-lapse picture of a starry sky. This kind of photograph uses a camera on a tripod and the photographer leaves the shutter open for a long time when taking it. The phot then records the paths taken by the stars across the sky.

a How can you tell that this photograph was taken looking to the north?

b What is the term for the central point that all the stars in the photo are moving round?

c The photograph shows you part of the circular paths described by the stars right in the north.
Explain why it is difficult to make a recording of the complete circle.

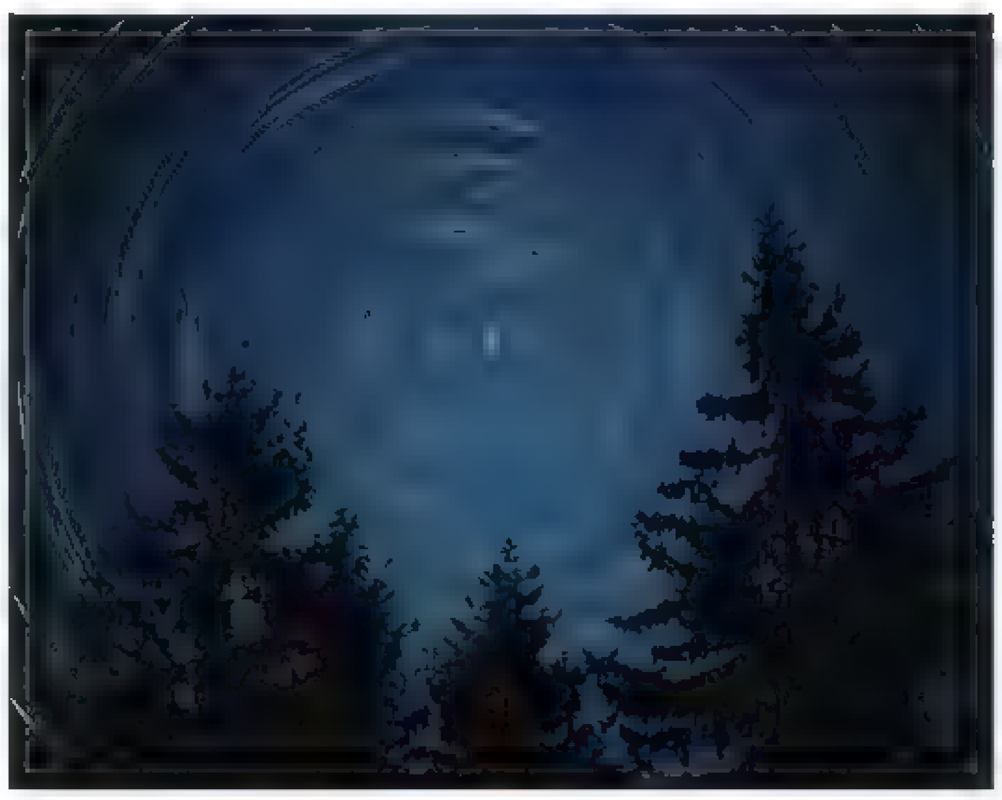


figure 10 A time-lapse picture of a starry sky.

4

In the Netherlands, the Pole Star (Polaris) is at an angle of 52° up in the sky. (Horizontal, directly in front of you, is 0° and vertical, directly above your head, is 90°).
How does the angle you see the Pole Star at change:

- **a** if you travel directly northwards from the Netherlands (for example to Norway)?
  Tip: sketch the globe and Polaris to help you picture the situation.
- **b** if you travel directly eastwards from the Netherlands (for example to Poland)?
- **c** if you travel directly southwards from the Netherlands (for example to Spain)?
- **d** if you travel directly westwards from the Netherlands (for example to Ireland)?

5

Figure 11 shows the sun, the Earth and the constellations of the zodiac. The drawing makes clear which directions you can see the sun and the stars in, but it is not to scale.

- **a** How does the Earth move around the sun in figure 11: clockwise or anticlockwise?
- **b** In which month is the sun (as seen from the Earth) in front of the constellation Pisces?
- **c** In which month is the sun (as seen from the Earth) in front of the constellation Virgo?
- **d** Which constellation of the zodiac is the sun in front of from early August onwards?

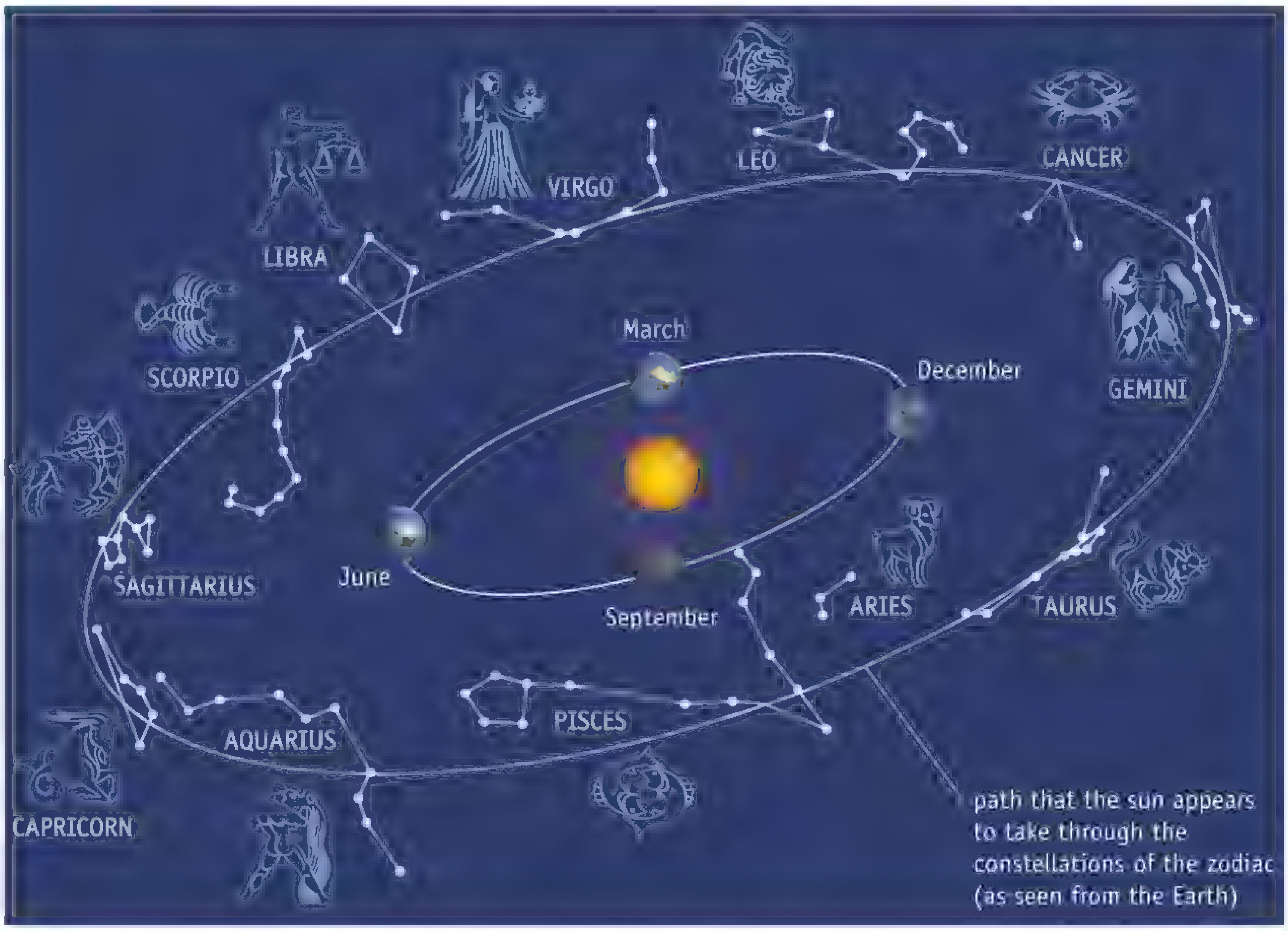


figure 11 The sun, the Earth and the zodiac (not to scale).

★ 6

In mid-March at about 02:00, you can see five complete constellations of the zodiac in the sky. From east to west, they are Libra, Virgo, Leo, Cancer and Gemini. See figure 11.

- **a** Which of these five zodiacal constellations rose last?
- **b** Which will be the next zodiacal constellation to rise in the east after 02:00?
- **c** Which zodiacal constellation will you be able to see setting in the west at the same time?
- **d** Which zodiacal constellation will rise, together with the sun, just before 07:00?

7

There are two points in the year when the day and night are exactly equally long. These are called the equinoxes (from the Latin *aequus* = equal and *nox* = night).

a What are the dates of the two equinoxes?

b Figure 12 is a drawing of the Earth at an equinox. The direction of the sun has been shown too.
Colour in the part of the Earth where it is night at the moment.

c Draw in the circle described around the North Pole by the Netherlands.

d How can you tell that the day and the night are exactly equally long?

e Are the equinoxes in the southern hemisphere on the same dates as in the northern hemisphere? Explain your answer.

figure 12 The Earth viewed from above the North Pole at an equinox.

★ 8

The Earth's axis is at a skew angle to the plane of the ecliptic, at 23° to a perpendicular to the ecliptic.
What would be strikingly different in the Netherlands (write down two things):

a if the Earth's axis was exactly perpendicular to the ecliptic?

b if the Earth's axis was at even more of a skew angle, for example at 35° to the ecliptic?

9

Figure 13 shows you what the moon looked like during a period of two weeks in October 2020. The times that the moon rose and set are given beneath each photograph.

a What can you say about the time of the moonrise each day?

b When does the moon rise in the morning and set in the evening, like the sun?

- ○ A at a new moon
- ○ B at the first quarter (waxing)
- ○ C at a full moon
- ○ D at the third quarter (waning)

c Where is the moon then with respect to the Earth and the sun?

d When does the moon rise in the evening and set in the morning, the opposite of the sun?

- ○ A at a new moon
- ○ B at the first quarter (waxing)
- ○ C at a full moon
- ○ D at the third quarter (waning)

e Where is the moon then with respect to the Earth and the sun?

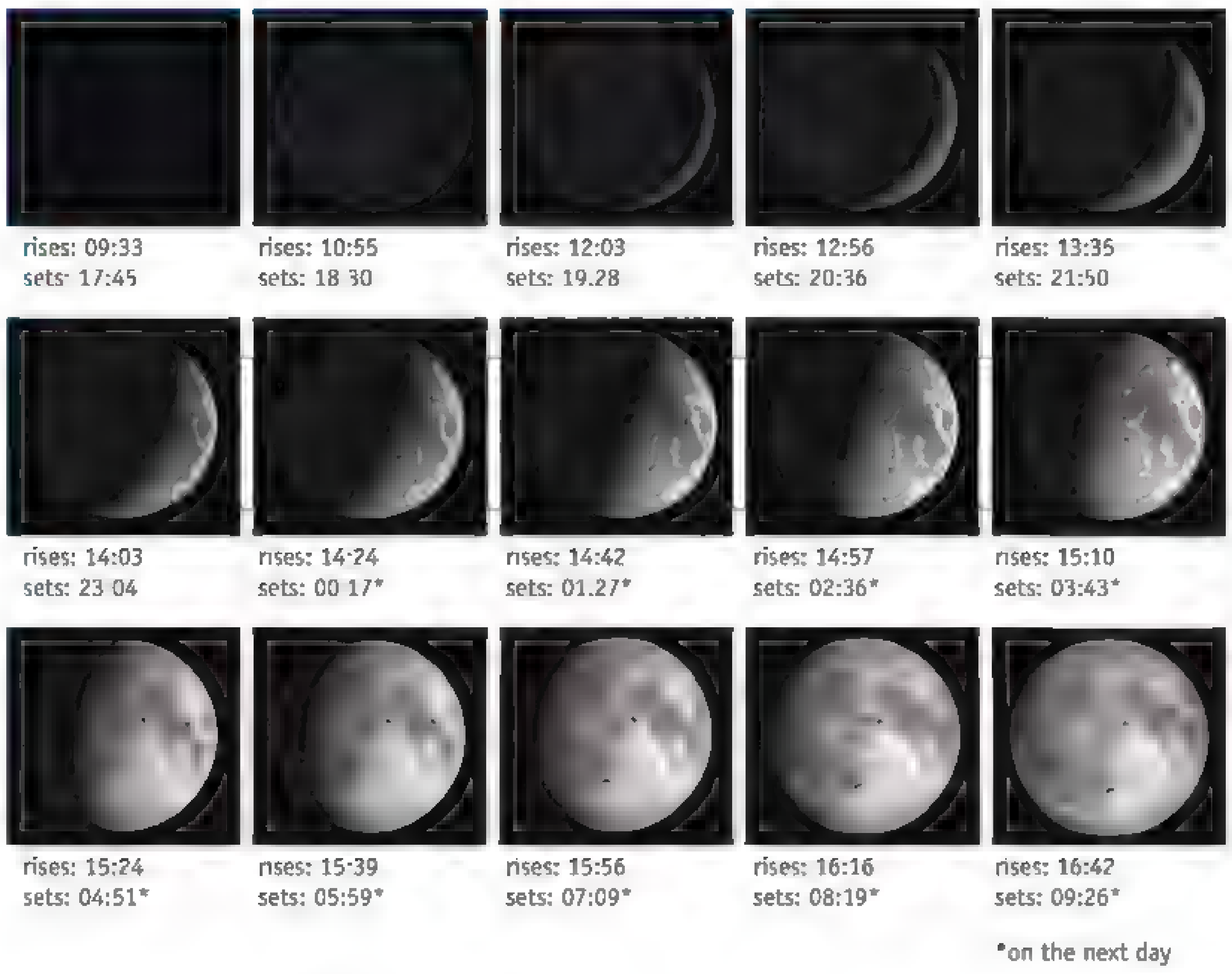


figure 13 Moonrise and moon setting times from 16 to 31 October 2020.

Test what you know with *Test yourself*.

EXTRA SOLAR ECLIPSES

10 Solar eclipses are often not total anywhere on the Earth. You then see that the moon has taken a large bite out of the sun's disc, but that's all. The sun is not fully eclipsed anywhere on the Earth then.
Explain how a partial eclipse can occur. Use the words 'umbra' and 'penumbra'.

★ 11 The area in which a solar eclipse can be seen moves across the Earth's surface very quickly. The solar eclipse of 14 October 2023, for example, will be seen first on the west coast of the United States and then ends about 4 hours later in the east of Brazil.
Write down two reasons why the moon's umbra moves across the Earth's surface.

12 Figure 14 shows a *lunar eclipse* (not to scale).

- **a** Fill in the names at the correct places: *sun – moon – Earth*.
- **b** Draw in the umbra of the Earth.
- **c** Is it possible for you to see a complete lunar eclipse from one place on the Earth's surface but only a partial one from another place? Explain your answer.
- **d** Suppose that there were people on the moon's surface, on the hemisphere that faces the Earth, during a lunar eclipse.
  What would they see during the lunar eclipse?

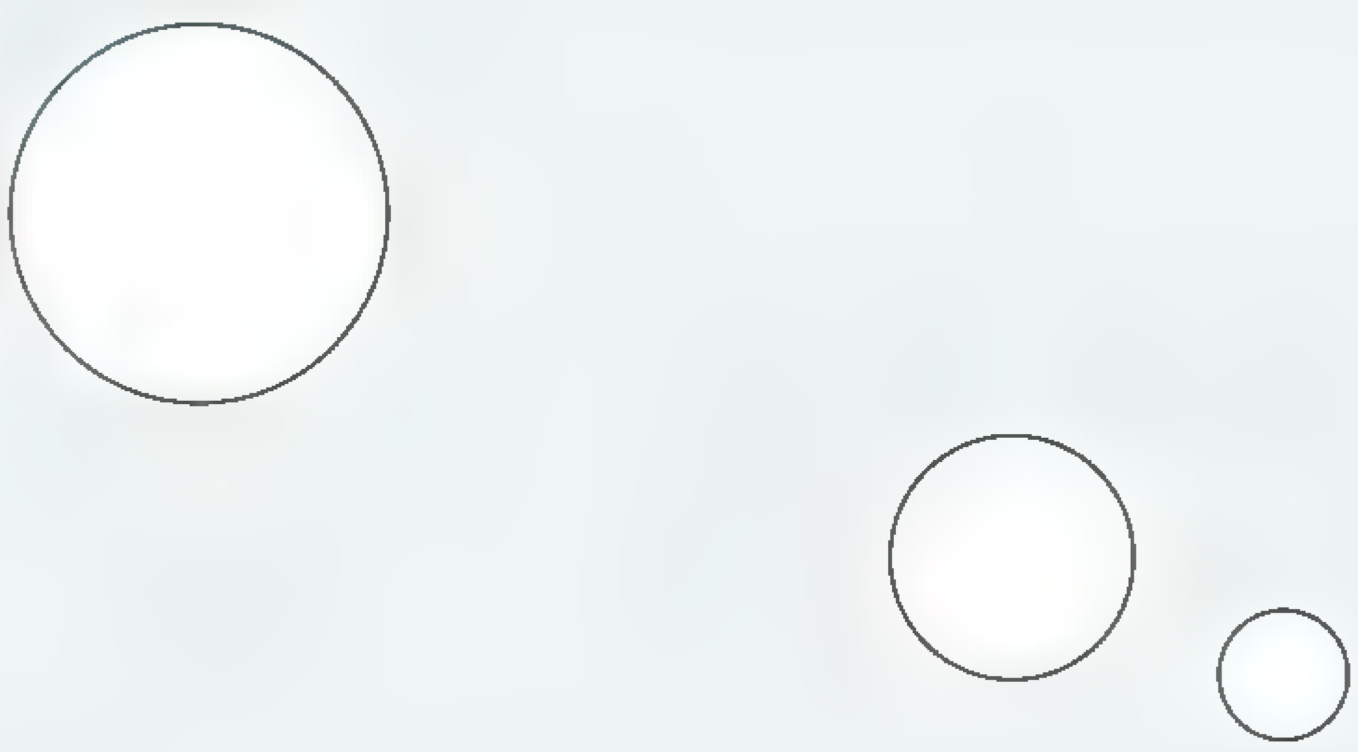


figure 14 A lunar eclipse (not to scale).

2 The solar system

LEARNING OBJECTIVES

7.2.1 You can explain how an astronomer can distinguish planets from real stars.
7.2.2 You can describe how the eight planets of the solar system move around the sun.
7.2.3 You can name the planets in sequence of how far from the sun they are.
7.2.4 You can state the most important differences between the terrestrial planets and the gas giants.
7.2.5 You can convert distances from km to AU and vice versa (also using powers of 10).
EXTRA 7.2.6 You can explain what comets are and how they look during their orbit around the sun.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	7.2.1	7.2.2	7.2.3	7.2.4	7.2.5	7.2.6
Remembering	1b, 3b	1ae		1cd	2abcd	
Understanding	3a	4c, 5bcde, 9a	5a, 8abc		2e	10abc, 11a
Using	4de	4ab, 6cde, 9bc	8de, 9d		7abcd	10d, 11bc
Analysing	3c	6ab				11d

As well as the Earth, seven other planets orbit the sun. Five of them can be seen clearly from the Earth and they were named back in Antiquity: Mercury, Venus, Mars, Jupiter and Saturn. Uranus and Neptune were only discovered later, in 1781 and 1846 respectively.

THE PLANETS

Seen from the Earth, planets look much like stars. With the naked eye, they are small spots of light. If you look at stars and planets through a telescope, though, there is a difference. A star then remains just a dot; the telescope only makes a star look brighter. But a planet becomes a disc, with its own specific appearance.

There is another important difference for astronomers. Stars have fixed positions in the sky and do not move relative to one another. That rule does not hold for the planets. Like the sun, they move through the twelve constellations of the zodiac. Each does that at a different rate: Mercury is quickest and Neptune slowest.

Figure 1 shows you a model of the solar system. The model is not to scale. In reality, all the distances are much greater. The sun and the planets are not to scale either. There is a third difference too. In the model, all the planetary orbits are shown in the plane of the ecliptic, but in reality they deviate from it a tiny bit, one planet more so than another.

figure 1 A model of the solar system (not to scale).

Planets move around the sun in an **ellipse**, a shape like a flattened circle. That means that they are closer to the sun at some moments than at others. Those differences are only small for most of the planets, though: their orbits are pretty much circles. As a result, their average distance from the sun gives you a good impression of their orbit. Mercury is the only one in which the differences are more significant.

THE TERRESTRIAL PLANETS

Mercury, Venus, the Earth and Mars are called the **terrestrial planets.** In terms of dimensions and composition, they are all fairly similar (figure 2). All four have a hard, rocky surface. On the inside, they are made of rocks and metals in either solid or liquid form. The Earth is the only terrestrial planet that is largely covered in water.

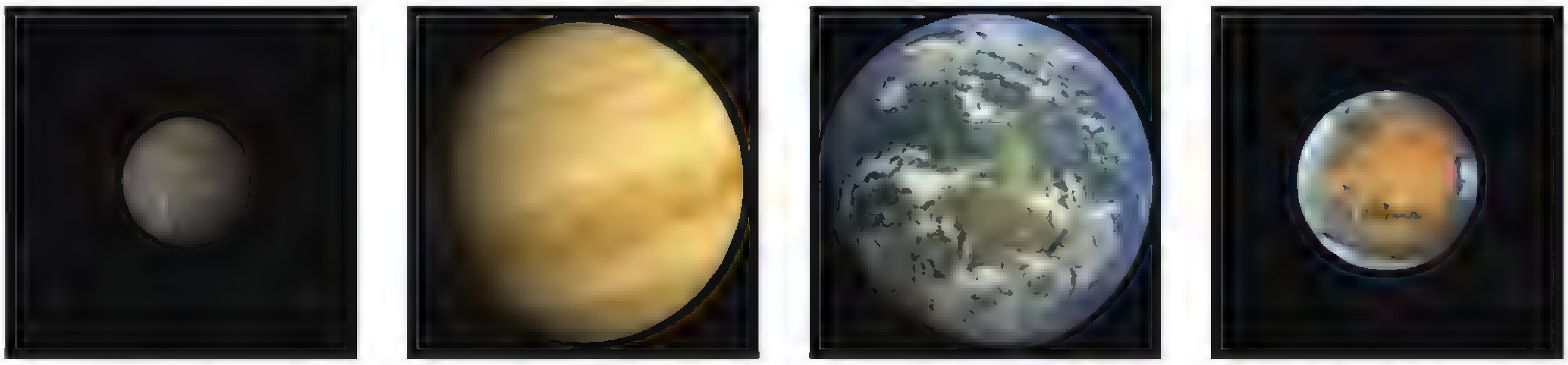


figure 2 The planets Mercury, Venus, the Earth and Mars, shown at the same scale.

Like the moon, you can only see the planets because they reflect light from the sun. Venus and Mars are closer to the Earth, so they are clearly visible. Because it is covered with white clouds, Venus is in fact one of the brightest heavenly bodies; only the sun and the moon give more light. You sometimes see Venus as the 'evening star' shortly after sunset or as the 'morning star' shortly before dawn.

Planetary exploration missions have landed on both Venus and Mars to make measurements and take photographs. Venus is so hot that an explorer cannot last for very long there. But explorer robots can sometimes last for years on Mars. The rover *Opportunity* operated for no less than 14 years, from 2004 to 2018. Thanks to explorers like these, we know well what the surface of Mars looks like (figure 3).

figure 3 A photograph of the planet Mars, taken by the planetary explorer *Curiosity*.

GAS GIANTS

The planets Jupiter, Saturn, Uranus and Neptune are called the **gas giants**. They are much bigger than the terrestrial planets (figure 4) and they are further from the sun. Jupiter and Saturn are the closest in and they are brighter in the sky than most stars. Uranus and Neptune are much further away. Uranus is just about visible with the naked eye, but you need a telescope to see Neptune.

The gas giants are made up largely of gases – no surprise there! From the outside, you can only see the upper layer of clouds that surround the planet. Beneath those clouds, though, there is no sturdy and rocky surface that you could land a spacecraft on. There is therefore no point sending a planetary rover: it would disappear without a trace into the deeper layers of the planet.

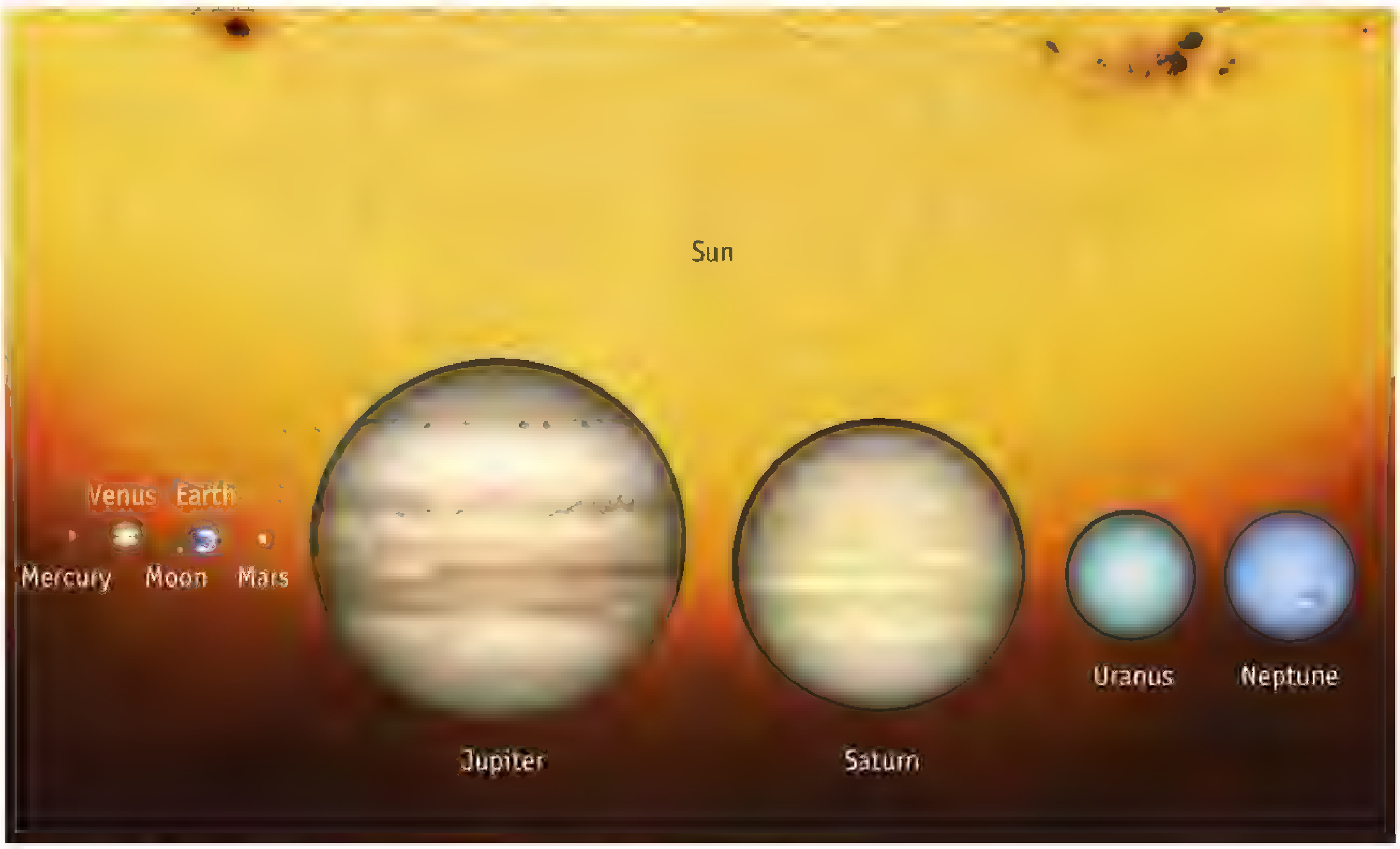


figure 4 The sun and the planets, drawn to the same scale.

DISTANCES IN THE SOLAR SYSTEM

EXP 2

Drawing the solar system to scale in a single figure is not easy. That is because the distances in the solar system differ so much. If you draw the orbit of Neptune so that it just fits on a piece of A4 paper, the orbit of Mercury is a tiny little circle with a diameter of 3 or 4 mm. So drawings of the solar system are almost never to scale.

Various ways have been thought up of representing the distances in the solar system. Astronomers often use powers of ten. They will for instance say the Neptune is on average $4.50 \cdot 10^9$ km from the sun. That is 4.50 billion kilometres. The combination 10^9 stands for $10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1{,}000{,}000{,}000$ or one billion.

There is a special unit for distances in the solar system, the astronomical unit (AU). This is a handy way of comparing distances in the solar system against each other. 1 AU is defined as 149,597,870,700 m – the average distance of the Earth from the sun. For the calculations in this chapter, you can use the rounded-off value of 1 AU = $150 \cdot 10^6$ km.

EXAMPLE EXERCISE 1

The average distance between Saturn and the sun is $1430 \cdot 10^6$ km (figure 5).
How many astronomical units is that?

given — the distance between Saturn and the sun is $1430 \cdot 10^6$ km
rounded off, the value of 1 AU is: $150 \cdot 10^6$ km.

required — the distance between Saturn and the sun in AU

working — You want to work out how many times 1 AU goes into $1430 \cdot 10^6$ km.

You do that by dividing: $\dfrac{1430 \cdot 10^6}{150 \cdot 10^6} = 9.5$ AU

Saturn is therefore nearly ten times as far from the Sun as the Earth is.

figure 5 The planet Saturn, with rings, photographed by the Hubble space telescope.

Table 1 gives some orbital data for the planets. It tells you how fast the planets move in their orbits about the sun, for instance. It is clear that there is a relationship there to the distance from the sun: the closer a planet is to the sun, the faster it moves. Mercury is moving about one and a half times as fast as the Earth and almost nine times faster than Neptune.

table 1 Orbital data for the planets.

[illegible]	average distance to the sun (AU)	orbital period in Earth years (y)	average orbital speed (km/s)	angle to the ecliptic (°)
Mercury	0.39	0.241	47	7.0
Venus	0.73	0.615	35	3.4
Earth	1.0	1.00	30	0
Mars	1.5	1.88	24	1.9
Jupiter	5.2	11.9	13	1.3
Saturn	9.5	29.4	9.7	2.5
Uranus	19	83.8	6.8	0.8
Neptune	30	164	5.4	1.8

From: NASA, Planetary Fact Sheet (metric)

Practice the concepts using the *Flash cards*.

EXTRA PLANETOIDS AND COMETS

As well as planets, there are also planetoids and comets orbiting the sun. These heavenly bodies are much smaller than planets. Planetoids are large, irregularly shaped blocks of rock and ice. There are a lot of them in the area between Mars and Jupiter at 2 AU to 3 AU from the sun, in which case they are usually known as 'asteroids' and this is the main 'asteroid belt'. There are also planetoids with orbits that come close to that of the Earth.

figure 6 The comet Hale-Bopp in 1997, at about 1 AU from the sun.

Comets are made of ice, mixed with dust and grit. They come from the outermost reaches of the solar system, beyond Neptune. Some comets have highly elliptical orbits that take them close to the sun. The sun's heat then makes some of the ice evaporate. The vapour creates an elongated, thin atmosphere around the comet – a tail that can be millions of kilometres long (figure 6).

Just occasionally, a planetoid or comet may collide with another heavenly body. A collision like that can cause a huge amount of damage. On a rocky surface, it will then create an impact crater: a large, round hole in the ground with a raised crate edge or ejected rock all round it (figure 7). The biggest impact craters have diameters of hundreds of kilometres.

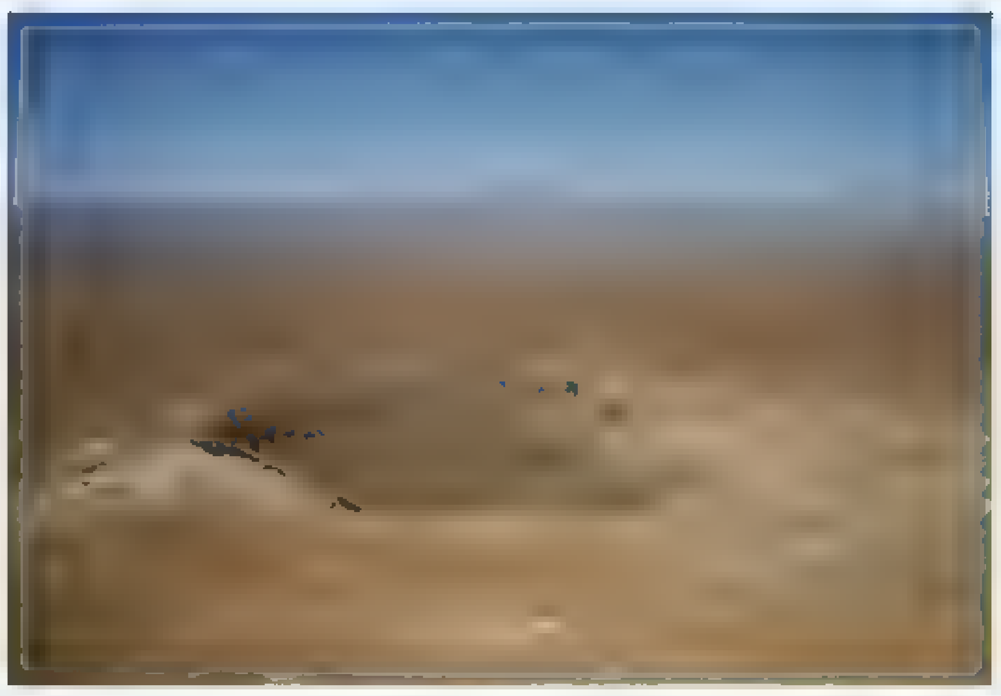


figure 7 This impact crater in Arizona (USA) is 200 m deep and 1200 m across.

COURSE MATERIAL

1

Complete.

a Planets move in .... round the sun; their orbits generally only deviate a little from being ....

b The planets themselves do not give off light; like the ...., you can only see them because they .... light from the sun.

c Mercury, ..., the Earth and Mars are called the terrestrial planets; they are much .... to the sun than the gas giants.

d For the four gas giants – ...., Saturn .... and Neptune – you can only see the outermost layer of .... around the planet.

e The closer a planet is to the sun, the .... it moves; .... is the faster-moving planet and .... is the slowest.

2

Neptune is on average $4.50 \cdot 10^9$ km from the sun.

a What number does the notation 10^9 stand for?

b You can also write the distance $4.50 \cdot 10^9$ km as 30 AU. What do the letters AU stand for?

c Rounded off, what is the value of 1 AU?

d Which planet is on average 1 AU from the sun?

e How can you convert a distance from km to AU?

IN PRACTICE

3

Long before there were telescopes, people in Antiquity distinguished between the planets and the 'ordinary' stars.

a How can you tell that a point of light in the sky is not an 'ordinary' star but a planet, if you have no instruments to help you?

b How do planets differ from stars if you look at them through a telescope?

c The word 'planet' means *wanderer*. It is derived from a Greek word meaning to *roam about* or *drift*. The term 'wandering star' was used for them in English in the past too. Explain the reasoning for that name.

4

Figure 8 shows the Earth and Mars at five different moments (numbered 1 through 5).

- **a** How can you see from the drawing that the Earth is moving faster than Mars?
- **b** Draw in the sun at the correct place in figure 8 and label it as the 'sun'.
- **c** At which moment is the distance between the Earth and Mars smallest?
- **d** How bright Mars is (as seen from the Earth) varies a great deal.
  During which period of figure 8 is Mars getting brighter?
- **e** During which period is Mars becoming dimmer?

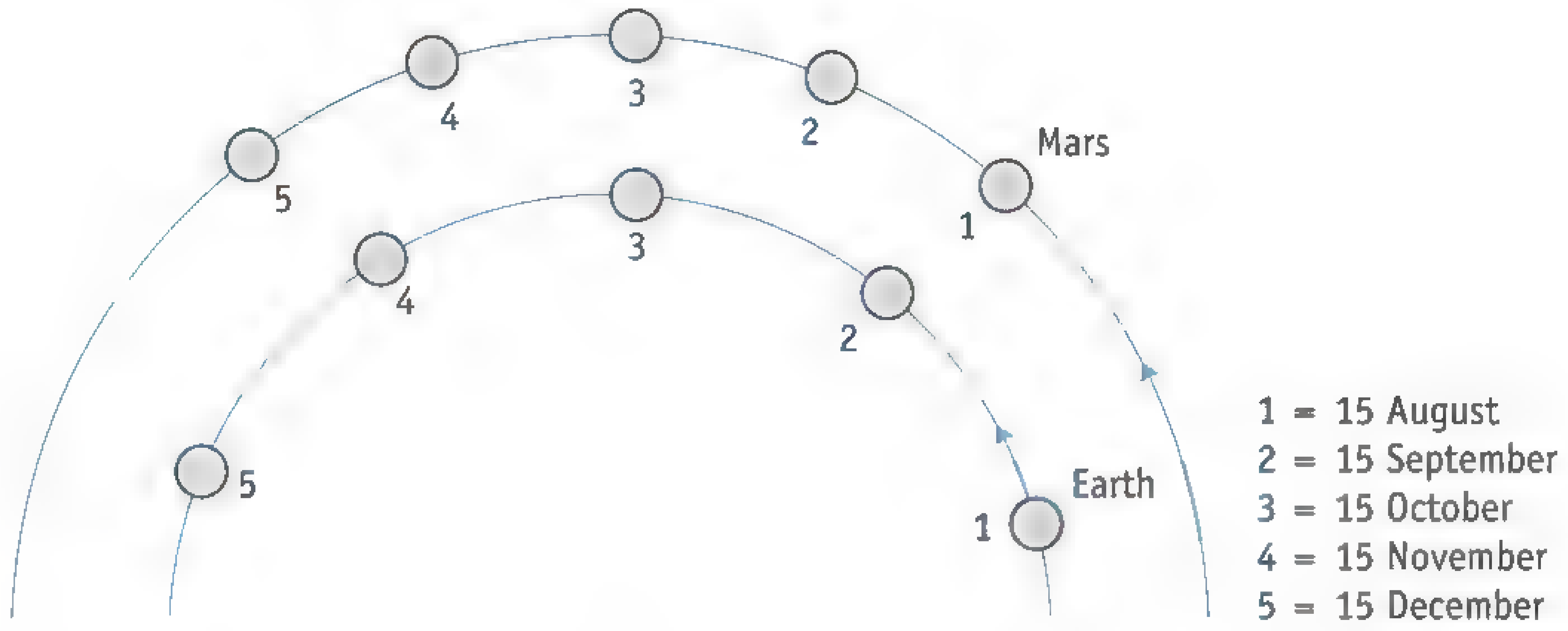


figure 8 Mars and the Earth during the second half of 2020 (not to scale).

5

This exercise is about the Earth's two neighbouring planets, Venus and Mars.
Select the correct options.

a	As seen from the Earth, which planet is always near to the sun?	*Mars / Venus*
b	Which planet has a shorter orbital period around the sun than the Earth?	*Mars / Venus*
c	Which planet can you sometimes see in the sky all night long?	*Mars / Venus*
d	Which planet can occasionally be seen transiting (moving across) the sun's disc?	*Mars / Venus*
e	Which planet can get further from the Earth during its orbit?	*Mars / Venus*

6

Figure 9 shows you the Earth, Venus and the sun. Venus has been drawn four times at four different positions in its orbit (A to D).

- **a** In which of these positions can Venus be seen as the 'evening star'?
- **b** In which of these positions can Venus be seen as the 'morning star'?
- **c** Like the moon, Venus also has phases. You need a small telescope if you want to see that.
  In which two positions is Venus at a quarter phase ('half full') as seen from the Earth?
  Tip: colour in the unlit parts of the planet in figure 9.
- **d** How does Venus look in the other two positions: largely illuminated or largely in the dark?
- **e** Sometimes only the dark, unlit side of Venus can be seen from the Earth. That is similar to the situation when there is a new moon.
  In figure 9, draw in where the planet is at that moment.

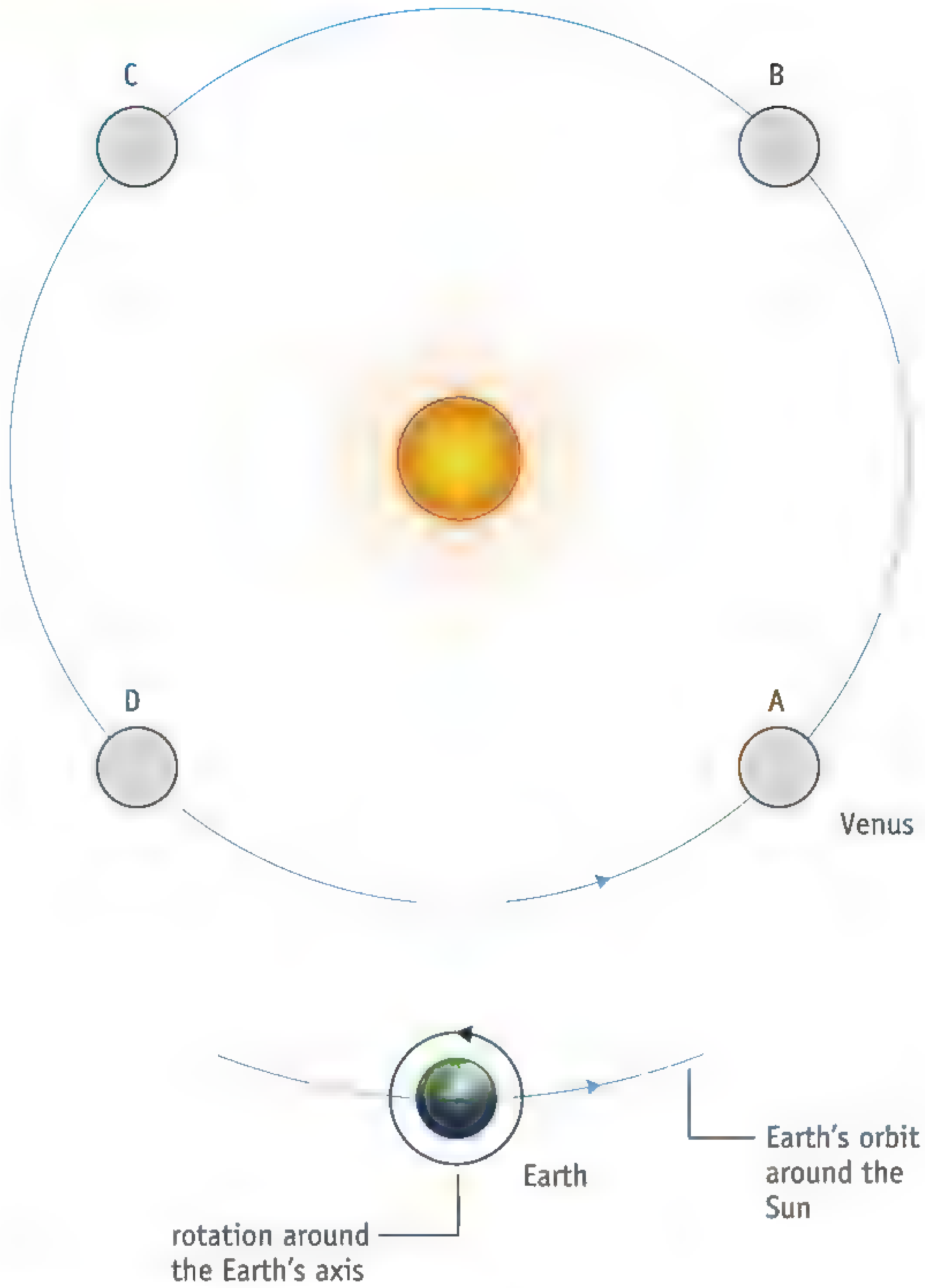


figure 9 Venus at four positions in its orbit around the sun (not to scale).

7 See the skills section on *Converting units*.
Four facts about the solar system are given below. Convert the distances in each of them to AU.

- **a** On 15 July 2020, the Earth reached its closest distance for Jupiter, 621 million kilometres. At that time, Jupiter was one of the brightest objects in the sky.
- **b** There are lots of asteroids (larger and smaller space rocks and rubble) between Mars and Jupiter, at distances of $3.15 \cdot 10^8$ to $4.95 \cdot 10^8$ km from the sun.
- **c** The photo in figure 10 was taken in 2017 by the planetary explorer Cassini. At that moment, the spacecraft was 1.4 billion kilometres from the Earth.
- **d** Until 2006, Pluto was reckoned to be the ninth planet. It was also the remotest planet, at an average of $5.91 \cdot 10^9$ km from the sun. It is no longer counted as a planet: instead, it is a dwarf planet.

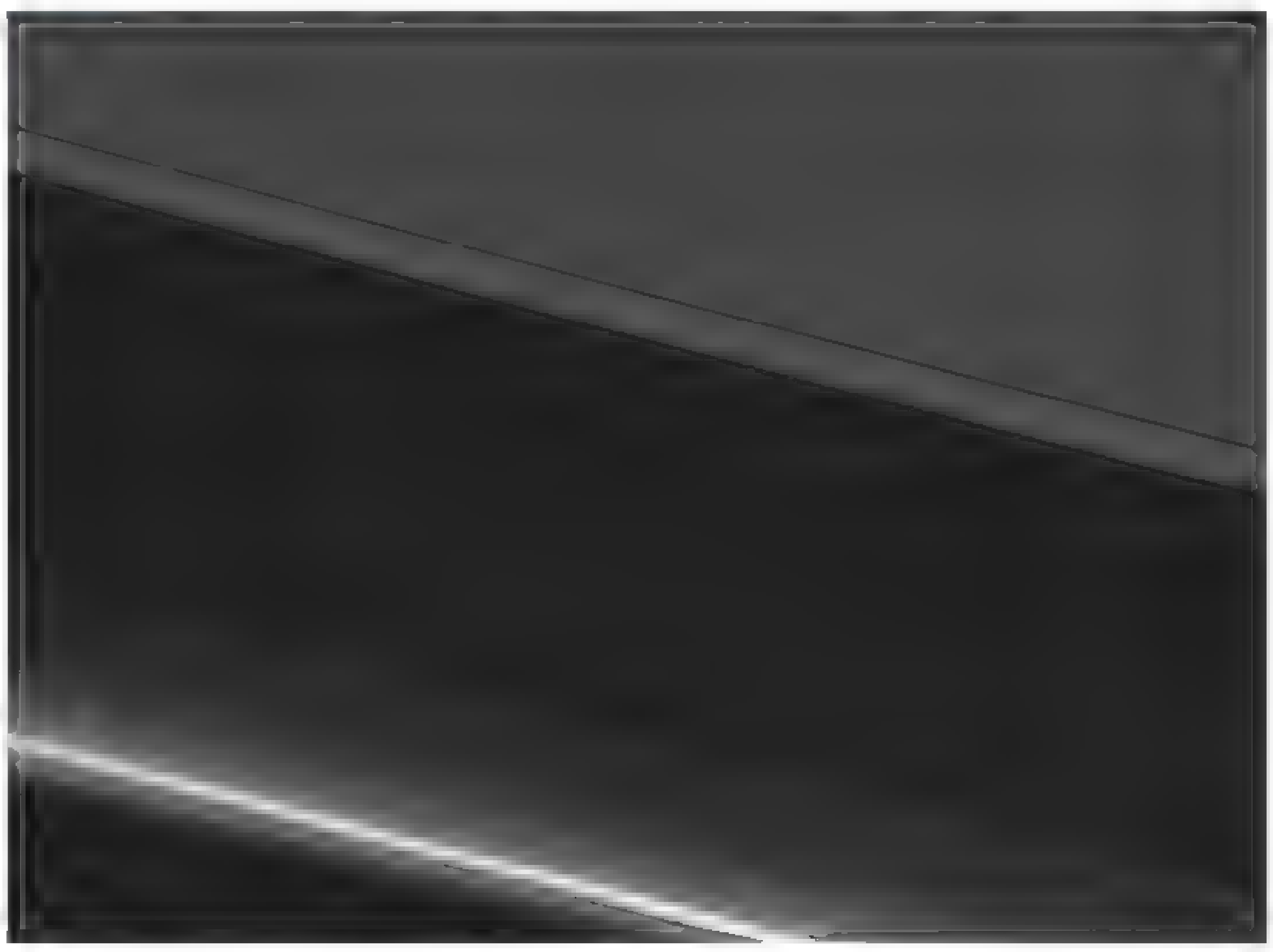


figure 10 Cassini took this photo of the Earth between two of Saturn's rings.

8 Aisha and Simone are laying out a model of the solar system on a football pitch of 105 by 65 m. For 1 AU in reality, they are using a distance of 10 metres in their model. For the sun, they put a softball in the centre of one of the goals (see figure 11). They then mark out the positions of each planet by sticking a flag in the ground at the right distance. They start with a flag for the Earth, 10 metres away from the softball.

- **a** Calculate the distances Aisha and Simone have to use for the other planets from the sun. Write the results down in the third column of table 2.
- **b** Which planets are so far away that Aisha and Simone can't place the flags on the football pitch?
- **c** How many football pitches in a row would you need if you wanted to stick the flag for Neptune in the ground at the right distance?
- **d** You can draw in the model made by Aisha and Simone in figure 11. For 1 AU in reality, you then need to use a distance of 2.0 cm when drawing the model.
  Calculate the distances you need between the planets and the sun on this scale. Round the results off to one decimal place and write them down in the right-hand column.
- **e** Draw in the planets at the correct distances from the sun. Then use a compass to draw their orbits across the football pitch. (The real orbits are indeed not perfect circular arcs, but the difference is small enough that you can ignore it here.)

table 2 Orbital data for the planets.

planet	average distance to the sun (AU)	distances in Aisha and Simone's model (m)	distances in figure 11 (cm)
Mercury	0.39		
Venus	0.73		
Earth	1.0	10	2.0
Mars	1.5		
Jupiter	5.2		
Saturn	9.5		
Uranus	19		
Neptune	30		

figure 11 You can lay out a model of the solar system on a football pitch.

9 The Earth takes less long to orbit the sun than Jupiter does. That means that the Earth 'overtakes' Jupiter regularly.

a Write down two reasons why Jupiter needs longer to orbit the sun once than the Earth does.

b Why does Jupiter seem brightest at the moments when it is 'overtaken' by the Earth?

c When is Jupiter least bright (as seen from the Earth)?

d Which planet does the Earth overtake more often: Jupiter or Mars? Explain your answer.

Test what you know with *Test yourself*.

EXTRA PLANETOIDS AND COMETS

10 Viewed through a telescope, planetoids (asteroids) look like small points of light, just like stars. You can recognize them from the fact that they move against the stars around them. Figure 12a shows you a photograph of a section of the sky. The point of light that the arrow is indicating is a planetoid.

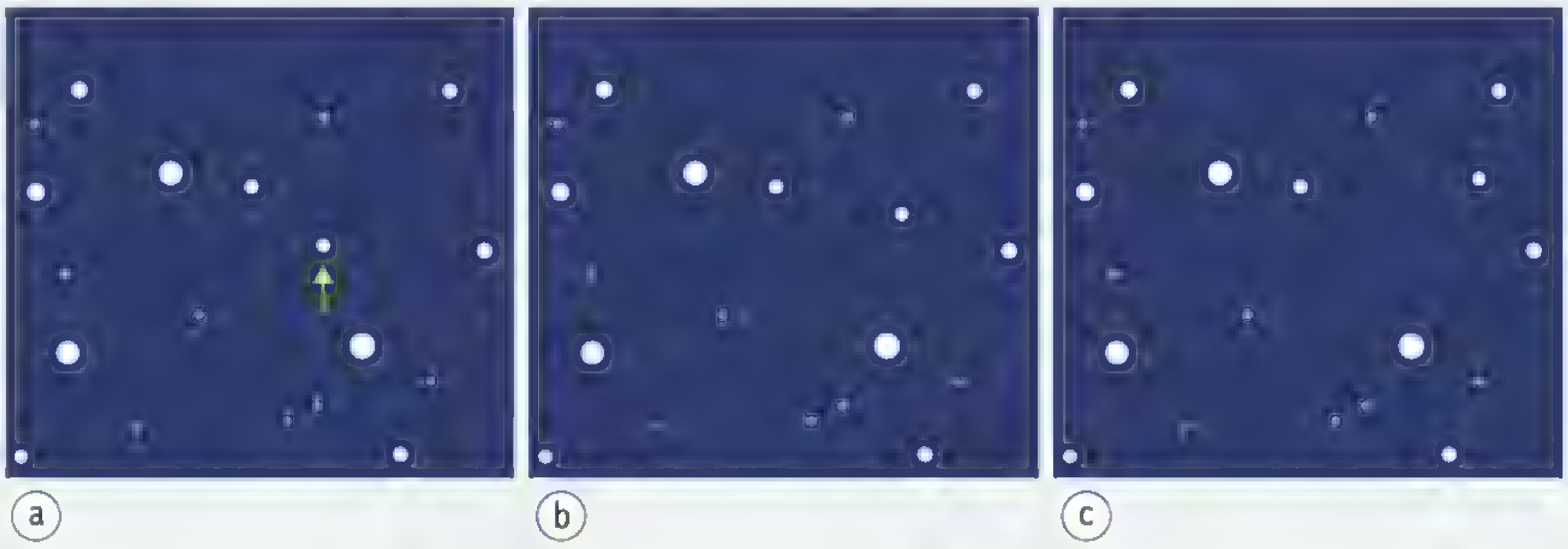
a Where is the same planetoid in figure 12b? Find it and put a circle round it.

b Find the same planetoid again in figure 12c and put a circle round that too.

c The word 'planetoid' means 'similar to a planet' or 'planet-like'.
In what way are planetoids similar to planets?

d Planetoids are much harder to see in the sky than planets. Explain why.

figure 12 Three images of the same piece of sky taken 10 minutes apart.



11 In 2013, astronomers started a major search for 'potentially dangerous' planetoids (figure 13). These planetoids are also known as "near Earth objects" or "Earth-grazing asteroids" because their orbits come close to or cross that of the Earth at times.

a Why are planetoids from the Asteroid Belt not a danger to people on Earth?

b On 9 February 2018, the planetoid 2018 CB passed the Earth at a distance of 64,000 km. The diameter of this space rock was about 40 m.
Calculate the passing distance in AU.

c Astronomers said afterwards that planetoid 2018 CB had only just missed the Earth.
Explain why an astronomer might put it that way.

d When astronomers find a new Earth-grazer, they often report its size and speed (with respect to the Earth).
Why would they report those two data items in particular?

figure 13

The search for Earth-grazers

There are an awful lot of lumps of space rock flying about in our solar system. Many of these pieces do not represent any danger to the Earth. But just occasionally we find a dangerous NEO (near Earth object) with an orbit that crosses the Earth's. Astronomers say such a planetoid is 'potentially dangerous' if it will come close to the Earth in future and is large enough to do a great deal of damage on impact. Researchers have now discovered more than 18,000 Earth-grazers.

The biggest ones are of course the easiest to find; it is estimated that 90% of all Earth-grazers that are large than a kilometre have now been detected. The challenge now is to detect as many as possible for the smaller planetoids (of sizes up to about 140 metres).

After: https://www.scientias.nl, 2020

3 A planetary atmosphere

LEARNING OBJECTIVES

7.3.1 You can explain what is meant by a 'vacuum' and a 'planetary atmosphere'.
7.3.2 You can explain why satellites can maintain their orbits around the Earth for many years.
7.3.3 You can list the differences between the atmospheres of the Earth, Venus and Mars.
7.3.4 You can explain why life on Earth needs oxygen and carbon dioxide.
7.3.5 You can explain what creates air pressure and why you often don't notice it.
7.3.6 You can say what instrument is used for measuring air pressure and what the units are.
7.3.7 You can explain why the air pressure decreases as you get higher in the atmosphere.
EXTRA 7.3.8 You can explain why people in space need a spacesuit.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES							
	7.3.1	7.3.2	7.3.3	7.3.4	7.3.5	7.3.6	7.3.7	7.3.8
Remembering	1b		1cde			2bcd	1a, 2e	9abcd
Understanding		3abc, 5b	8a	5d	2a		5c	10d
Using	6a		8bc		6bc		4ab, 5e, 7abc	10abc
Analysing		5a	8d					

Around the Earth, there is a layer of air that is a few hundred kilometres thick. That is very little indeed, compared to the dimensions of the Earth itself. Even so, without that thin layer, life on Earth would not be possible.

THE VACUUM BEYOND THE ATMOSPHERE

The universe consists almost entirely of empty space. There is absolutely nothing there, not even any stray molecules: just space with nothing in it at all. If an object is moving through empty space, there is nothing it has to push aside. And nothing to slow its movement down. Empty space like that with no molecules at all is called a **vacuum**.

Like many other planets, the Earth has an **atmosphere**. That is the name for the mixture of gases that forms the outermost layer of a planet (figure 1). Atmospheres often contain clouds that are made up of tiny, floating droplets of liquids. The planet Venus has such a thick layer of cloud cover that the surface of the planet is never visible.

figure 1 You can see the Earth's atmosphere on this satellite photograph.

The higher you get in a planet's atmosphere, the more rarefied it becomes (the thinner the gases around you become): the number of molecules per cubic metre is less. So it is not really possible to say how thick the atmosphere layer is: as you get up high enough, it gradually blends into the vacuum of space. By about 1000 km, you're pretty much completely beyond its limits.

There are all kinds of artificial satellites orbiting the Earth that have been put into orbit there by rockets. If a satellite is high enough above the atmosphere, there are no molecules there to slow it down. The satellite then retains the speed that it was given during the launch. It means that it can continue to orbit the Earth for years, just like the moon does.

A MIXTURE OF GASES

The Earth's atmosphere consists of 78% nitrogen (N_2) and 21% oxygen (O_2). It also contains small amounts of other gases, such as argon (Ar) and carbon dioxide (CO_2). That mixture of gases is what we call air. The atmosphere also contains water vapour (H_2O), but the amount of water vapour per cubic metre can vary widely.

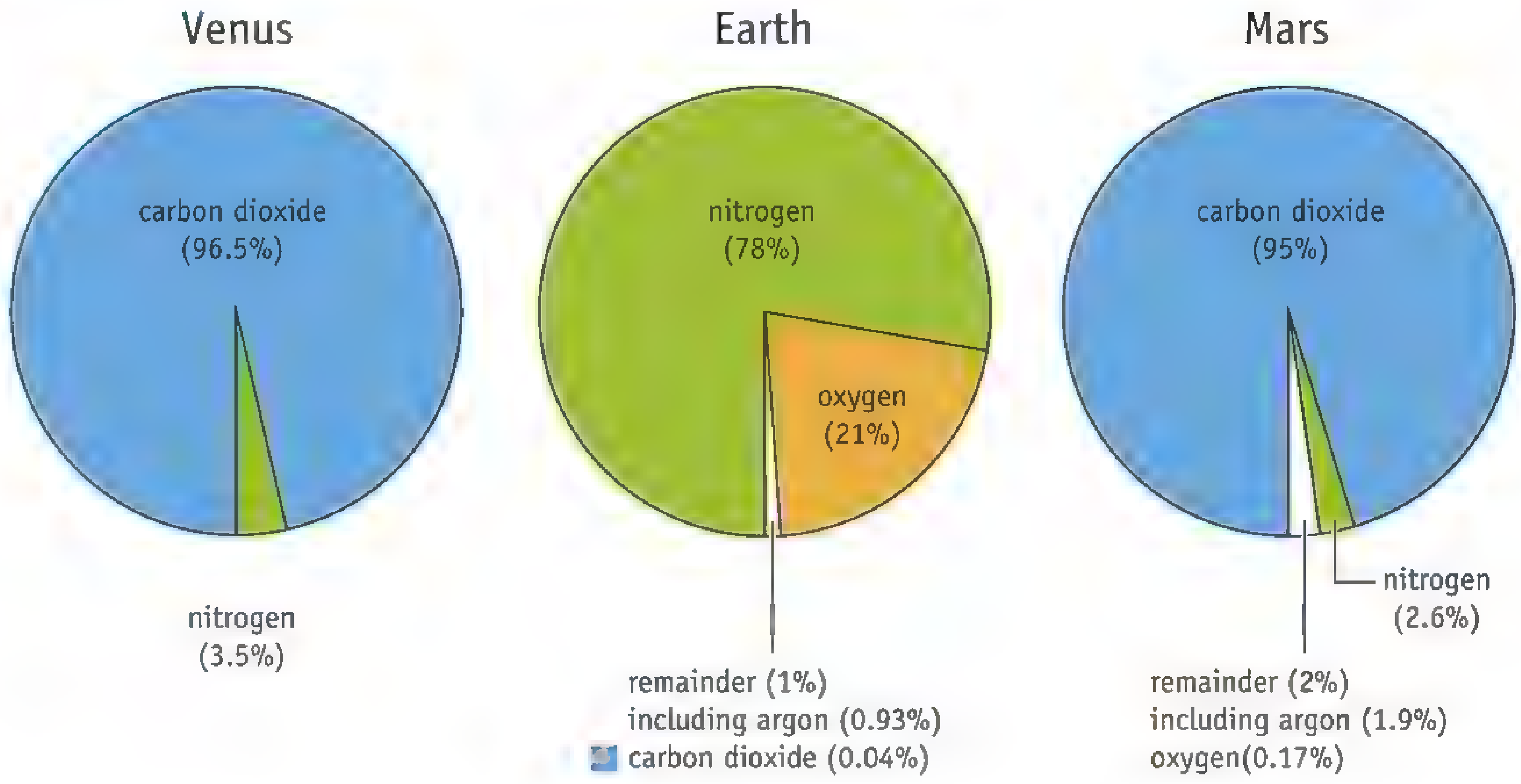
Oxygen is indispensable for the people (and animals) living on the Earth. Your body needs a constant supply of oxygen if it is to function (figure 2). Your lungs make sure that your body is always getting new oxygen. In your lungs, oxygen is absorbed into your blood from the air that you inhaled. The blood then transports the oxygen to every part of your body.

figure 2 A pilot flying very high up gets extra oxygen from an oxygen mask.

Air contains just 0.04% carbon dioxide. Even so, this gas is just as indispensable as oxygen for life on Earth. Plants need it so that they can grow. Carbon dioxide helps the atmosphere retain heat, keeping the Earth at a liveable temperature. There can be a problem if the levels of carbon dioxide get too high, making the Earth heat up too much.

The atmospheres of Venus and Mars have a completely different makeup to the Earth's air (figure 3). On both those planets, carbon dioxide is the main component. There is little or no oxygen. People could not possibly survive in an atmosphere like that. They would die immediately from the lack of oxygen.

figure 3 The composition of the atmospheres of Venus, Earth and Mars.

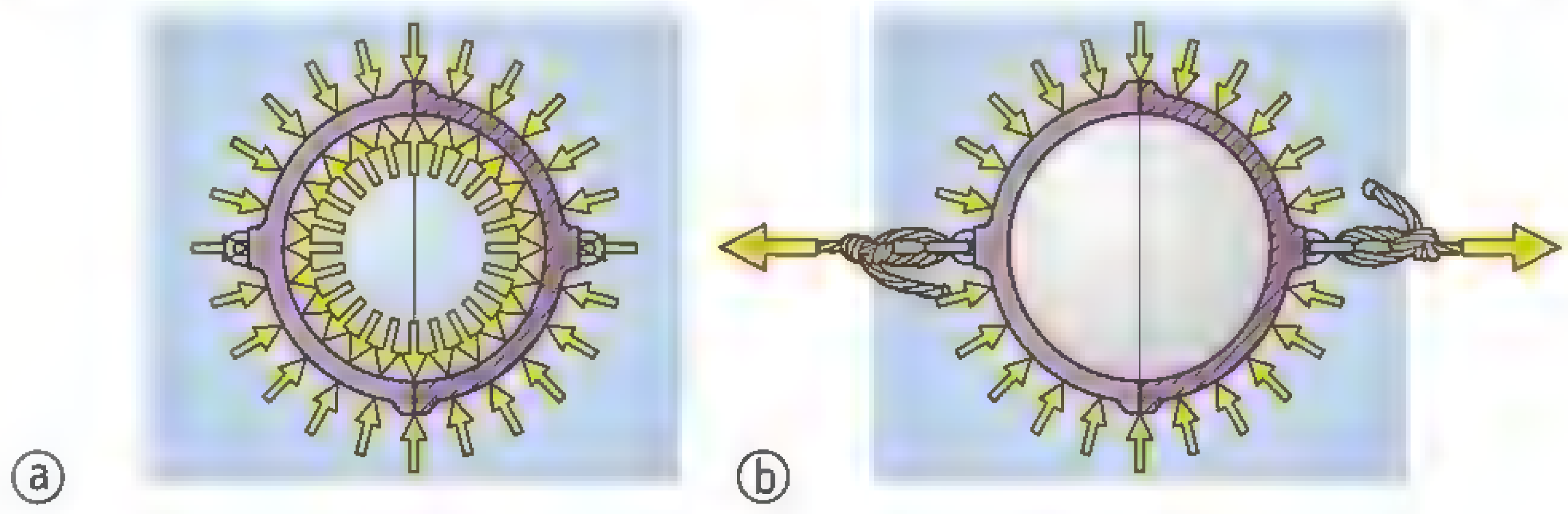


AIR PRESSURE

You live out your life on the surface of the Earth, down at the bottom of the Earth's atmosphere. There is air all around you and above you. Although the density of air is low, all that air above your head does nevertheless represent quite a weight. This means that the air exerts pressure on everything that is on the Earth. This pressure is known as the **air pressure** or **atmospheric pressure**.

You do not generally notice the air pressure at all. That is why all sorts of experiments have been thought up that show you how much air pressure there is. A famous example is the experiment known as the 'Magdeburg hemispheres'. In this experiment, two hollow hemispheres (half spheres) are placed up against each other and the air is then pumped out from inside them. It is then impossible to pull the two hemispheres apart (figure 4).

figure 4 The counter-pressure disappears when the air enclosed by the two hemispheres is pumped out.



When you place the two hollow hemispheres together, they do not stick together spontaneously. As long as there is still air inside them, you can easily pull the two halves apart. The air that is inside the hemispheres exerts a **counter-pressure** that is just as strong as the air pressure outside (figure 4a). The air pressure and the counter-pressure then balance each other out.

That changes if you pump out the air from between the two hemispheres. There is no longer any counter-pressure then. All that remains is the air pressure from the outside, which presses the half spheres very firmly together (figure 4b). Note that this pressure comes from all directions at once, not just from above!

MEASURING THE PRESSURE

You can use a **barometer** to measure the air pressure. Meteorologists generally use units of hectopascals (hPa) for the air pressure. This is derived from the official unit of pressure, the pascal (Pa): 1 hPa = 100 Pa. The weather station in figure 5 has a digital barometer. It is saying that the air pressure is 983.1 hPa. That is almost 100,000 Pa.

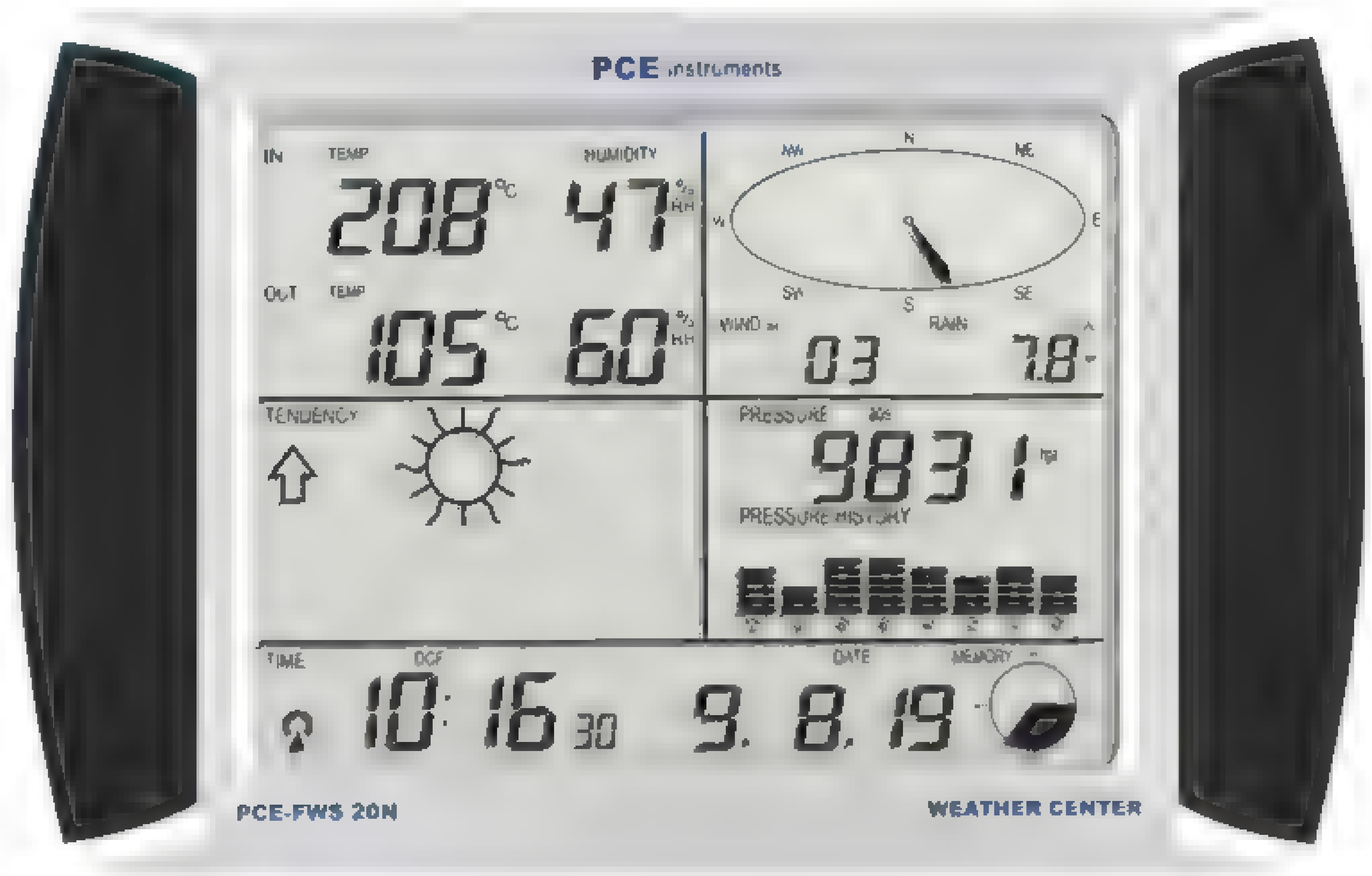


figure 5 The display of a digital weather station, showing the air pressure at the bottom right.

If you look at a barometer regularly, you will notice that the air pressure is not constant. That does not mean that the air pressure can take on just any value, though. The air pressure at sea level is almost never lower than 950 hPa or higher than 1050 hPa. The average air pressure at sea level is 1013 hPa. This value is also known as **standard pressure.**

Air pressure decreases with height: the higher you go, the lower the air pressure gets (figure 6). This is because the amount of air still above your head becomes less and less as you ascend. At an altitude of 5.5 km above sea level, half the molecules in the atmosphere are already below you. The air pressure at that height is therefore only half the pressure at sea level.

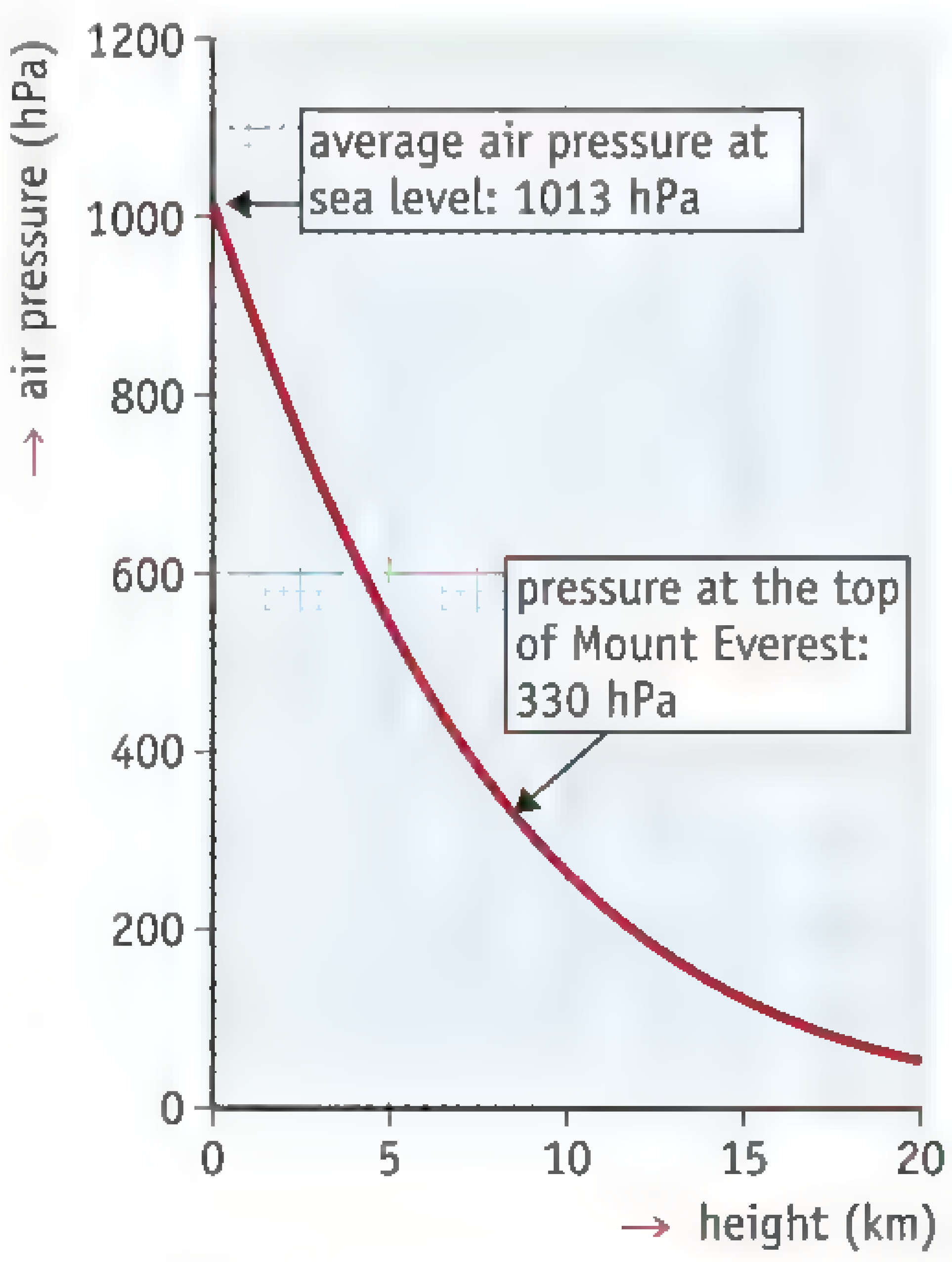


figure 6 The relationship between altitude and air pressure.

The atmospheric pressure on every planet is different. And they are big differences too. The pressure on the surface of Venus is very high, at about $92 \cdot 10^3$ (92,000) hPa. That is over ninety times higher than standard Earth pressure. The pressure on Mars, though, is much lower than on Earth. It fluctuates there at around 6.1 hPa, which is only 0.6% of the standard pressure on Earth.

Practice the concepts using the *Flash cards*.

EXTRA SPACESUITS

Your body has evolved to function at atmospheric pressures of about 1000 hPa. If you go higher in the atmosphere, the pressure decreases. Your body can adapt reasonably well up to heights of about 5 km. But problems occur pretty quickly above that. Passenger planes therefore have a pressure cabin, so that the passengers are not affected by the low pressure outside the plane.

The problems are even greater in the vacuum of space. Without protection, you could not survive there for more than a couple of minutes at most. If you are going to do anything in space, you absolutely must have a spacesuit (figure 7). That suit provides oxygen for its wearer, as well as removing the exhaled carbon dioxide, making sure the working temperature is correct and protecting against fast-moving space debris.

One key function of a spacesuit is exerting pressure on the body. To do that, there are airtight pockets everywhere inside the spacesuit that are inflated for a spacewalk. This means that the pressure exerted on the body is the same as the pressure in the astronaut's lungs. This prevents the lungs from expanding a long way and damaging the sensitive lung tissue.

figure 7 An astronaut in a spacesuit during a spacewalk.

COURSE MATERIAL

1

Complete.

a The higher you get in a planet's atmosphere, the more .... the gases around you become: the number of .... per cubic metre gets less and less.

b Outside the ...., there is only empty space. Empty space like that, where there are no molecules at all, is called a ....

c Air is a mixture of various gases. The two main components are .... (78%) and .... (21%).

d The atmospheres of the planets Venus and .... consist largely of .... People would immediately suffer from a lack of .... in an atmosphere like that.

e The atmospheric pressure on .... is much higher than it is on Earth, whereas the atmospheric pressure on .... is much lower (only 0.6% of the standard pressure on Earth).

2

Answer the following questions.

a What causes the pressure that the atmosphere exerts on you?
b What measuring instrument can you use for measuring air pressure?
c What units do meteorologists mostly express the air pressure in?
d What is the average atmospheric pressure at sea level?
e At what altitude is the air pressure 50% of the pressure at sea level?

IN PRACTICE

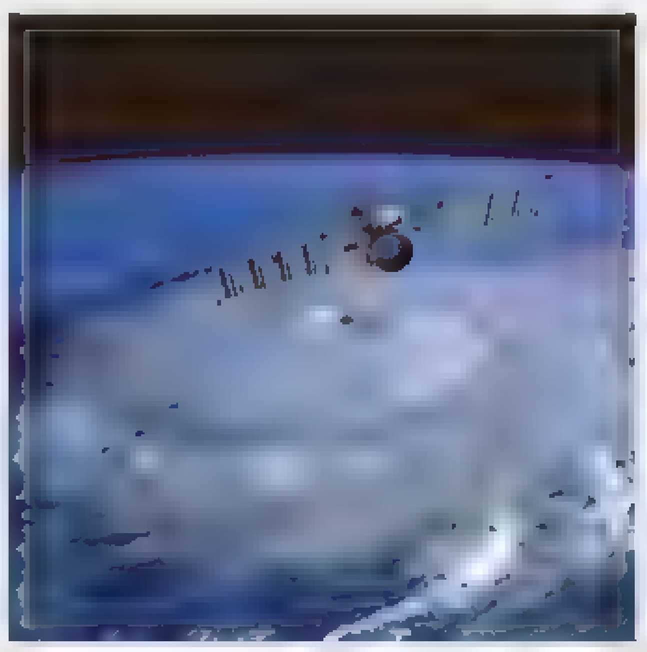
3

Artificial satellites have relatively low orbits around the Earth an only a limited lifespan. A website (figure 8) explains why.
Which data items in figure 8 tell you:

a that there are still a few molecules of air up at heights of 1000 km above the Earth?
b that there are nevertheless only a very few molecules indeed at 800 km above the Earth?
c that there are significantly more molecules at a height of 300 km than there are at a height of 400 km?

figure 8 Information about the lifespan of a satellite.

The end of a satellite



A satellite orbiting around the Earth at a height of less than 1000 km falls back into the atmosphere after a certain time. It is then burned up by the enormous heat that is created by friction with the air.
How long it takes before a satellite comes down depends on its original orbital height. At 800 km, it takes a couple of hundred years; at 400 km no more than a single year and at 300 km it is just a couple of months.
In general, satellite operators do not wait until a satellite comes down naturally. They move 'old' satellites out to a safe and stable final orbit, or they opt for a speedier return into the atmosphere.

4 Mountaineers sometimes take cylinders of oxygen up with them.

a Why do most climbers need extra oxygen to climb the highest peaks in the Himalayas?

b Why do mountaineers not need to take oxygen cylinders with them when they go climbing in the Alps?

5 The International Space Station (or ISS) has been orbiting the Earth at a height of over 400 km since 1998. The station consists of separate modules that are built on Earth. The modules are then brought into orbit using a rocket and then connected up to the ISS. As a result, the station has kept growing since 1998 (figure 9).

a The ISS moves at a speed of 27,600 km/h. Even so, the station is not streamlined in the way that fast planes and rockets are on Earth.
Explain why there is no need for the ISS to be streamlined.

b The ISS descends about 100 m every day. To get it back up to the correct height, a rocket motor is fired regularly. That is known as a reboost.
Explain why the ISS needs a regular reboost.

c The ISS modules that people stay in are filled with air. Those modules are pressurized to 101.3 kPa as a result.
Convert that pressure to hPa. What do you notice?

d The air on board the ISS has the same composition as the Earth's atmosphere. To keep that atmosphere balanced, a device is used that makes oxygen from water. There is also always an extra store of oxygen on board.
Why is new oxygen continually needed on board the ISS?

e The pressure in the ISS is monitored carefully. If the pressure begins to fall suddenly, the alarm is raised.
What has probably happened then?

figure 9 The International Space Station or ISS.

6

Jake puts a half-inflated balloon under a glass bell jar. He then connects up an air pump that sucks the air away from under the bell jar (figure 10).

a What does the balloon look like when almost all the air has been pumped out from under the bell jar?

b Give an explanation for this. Use the terms 'air pressure' and 'counter-pressure'.

c You can substitute a dab of shaving foam or a soft marshmallow for the balloon. Explain why you then see something similar happen.

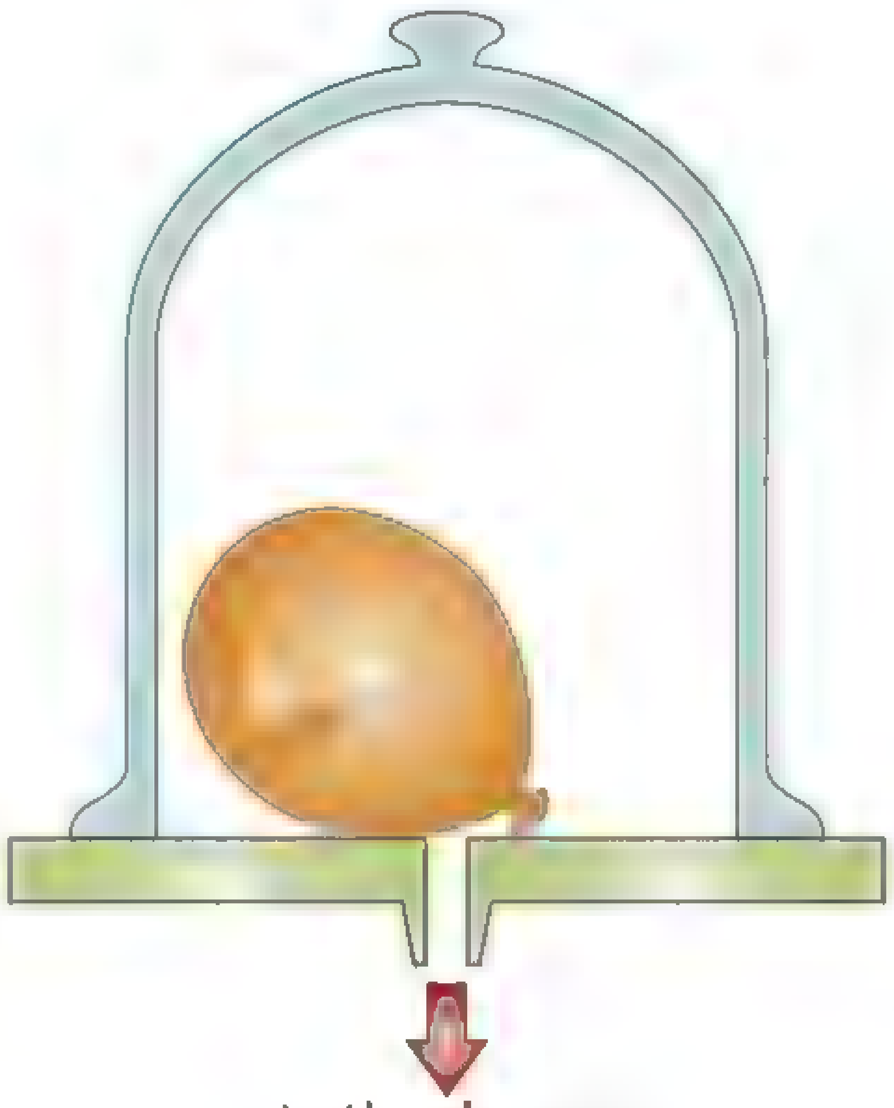


figure 10 An experiment with a half-inflated balloon.

7

If you go up a steep hill quickly in a car, it can affect your ears. A pressure difference has been created between the outside air and the air behind your eardrum (figure 11).

a On which side of the eardrum is the pressure greater?

b When you go back down the hill, your ears may start hurting again. On which side of the eardrum is the pressure greater now?

c You notice pressure differences most strongly if your Eustachian tubes are blocked. Explain why.

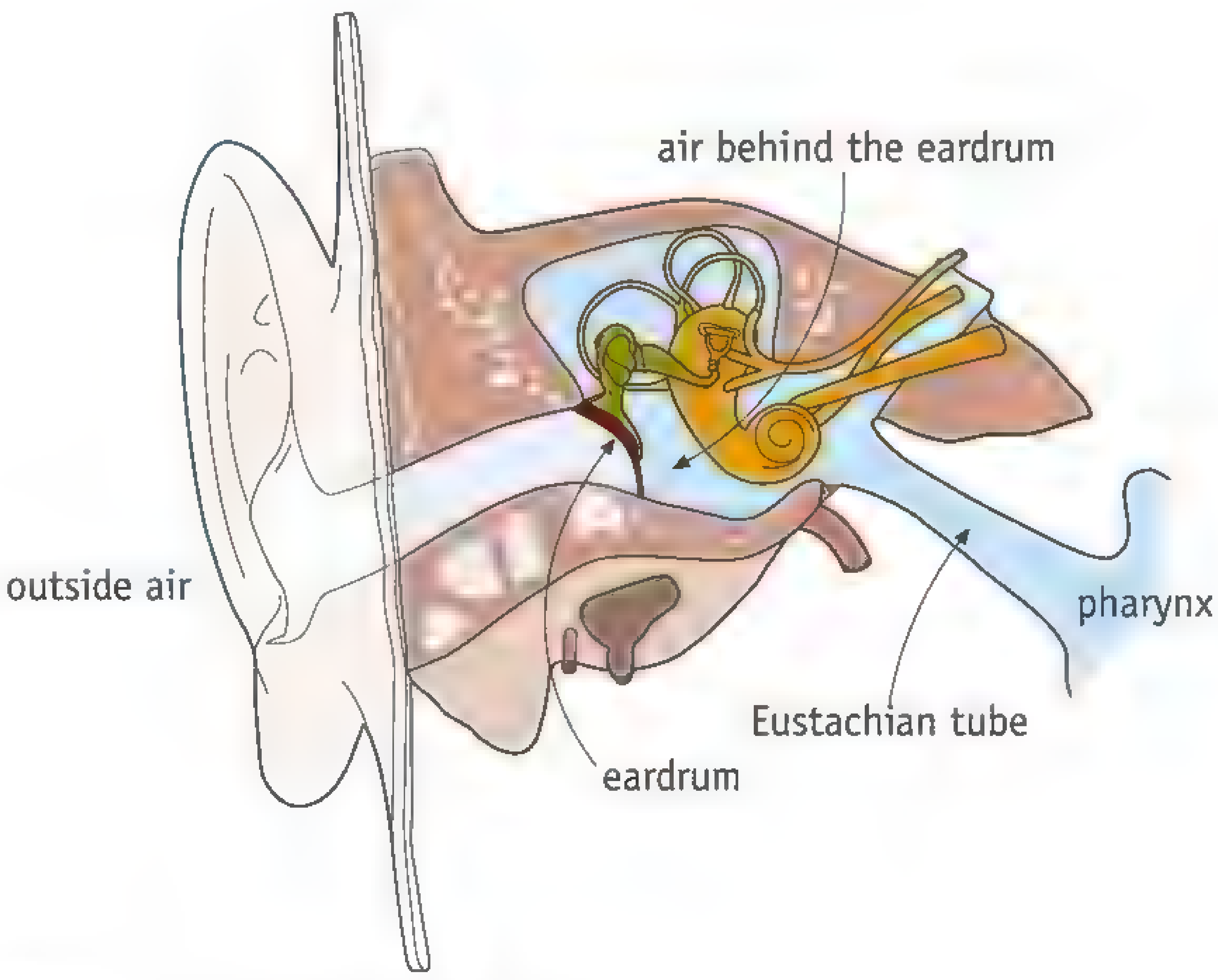


figure 11 Cross-section of an ear.

★ 8 On the KNMI website, there is an article about the greenhouse effect on the Earth, Venus and Mars (figure 12).

- a Would very much change on the Earth if there was no natural greenhouse effect? How can you tell?
- b The greenhouse effect on Venus is much stronger than the greenhouse effect on Earth. What two reasons for that does the article give?
- c Why is the greenhouse effect much less on Mars than it is on Earth?
- d The greenhouse effect described in the article is without any doubt beneficial to life on Earth.
  So why is the greenhouse effect named so often in the media as a problem?

figure 12 An article on the KNMI website.

The greenhouse effect on Earth and on its neighbouring planets

On Earth, the way the atmosphere acts like a greenhouse is largely determined by water vapour and carbon dioxide. Together, those two gases are responsible for a natural greenhouse effect of 33 °C.
The neighbouring planets, Venus and Mars, have atmospheres that consist almost entirely of the greenhouse gas carbon dioxide. Because of the very high air pressure on Venus, its atmosphere has a much higher mass of carbon dioxide than the thin atmosphere of Mars.
Venus is the planet where the greenhouse effect has run riot, increasing the surface temperature by something like 500 °C. On Mars, the natural greenhouse effect is only about 3 °C.

Test what you know with *Test yourself*.

EXTRA SPACESUITS

9 Complete.

- a Up to heights of about .... km above sea level, your body is able to adapt as the air pressure gets ....
- b Passenger aircraft has a .... in which the pressure is much .... than the thin air at a height of 10 km.
- c A spacesuit provides enough .... for the wearer to breathe and removes the exhaled .... too.
- d A spacesuit exerts a pressure on the .... of the astronaut that is the same as the pressure in their ....

10 The ISS space station is filled with ordinary air at 1013 hPa (see Exercise 5). But during a spacewalk, an astronaut breathes pure oxygen at a pressure of 297 hPa.

- **a** What pressure must the various airtight compartments in the spacesuit be inflated to?
- **b** What would go wrong if an astronaut was to breathe ordinary air at 297 hPa?
- **c** Having the astronaut breathe pure oxygen allows the pressure in the spacesuit to be kept lower.
  Explain why a lower pressure gives an astronaut more freedom of movement. Tip: think about pumping up a bicycle tyre.
- **d** The outermost layers of a spacesuit are made of a fabric that is also used for bulletproof vests. This fabric is intended to stop micrometeorites (fast-moving particles of space dust and grit).
  What would go wrong if a micrometeorite punched a hole in one of the airtight compartments of the spacesuit?

4 The structure of the universe

LEARNING OBJECTIVES

7.4.1 You can use a star chart to find stars, planets and constellations.
7.4.2 You can explain what a star is and that the sun is actually a very ordinary star.
7.4.3 You can explain how you can use triangulation to measure the distance to a star.
7.4.4 You can explain that a lightyear is a unit of distance, not a unit of time.
7.4.5 You can convert distances from km or AU into lightyears and vice versa (using powers of 10).
7.4.6 You can explain what a galaxy is and what you can see of our 'own galaxy'.
7.4.7 You can explain in general terms what current insights into the structure of the universe are.
EXTRA 7.4.8 You can explain what exoplanets are and how astronomers detect them.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES							
	7.4.1	7.4.2	7.4.3	7.4.4	7.4.5	7.4.6	7.4.7	7.4.8
Remembering		1a, 2b	1bc	1d	8a	1e	2e	
Understanding	3abcde	2a	5abcd, 6bcd		8b	2c	2d	10abc
Using			6ae		7ab, 8c	7cd	9	10d, 12
Analysing	4ab							10e, 11

The universe is inconceivably big. That makes it difficult to measure distances in the universe reliably. Astronomers have developed special measurement methods for this. This has let them build up a picture step by step of the structure of the universe outside our solar system.

A STAR CHART

EXP 1 A **star chart** or 'celestial map' is a representation of the stars in the sky on a cloudless night (figure 1). The stars are shown on this kind of map as small dots. The brighter a star appears, the larger the dot on the map. That does not mean that a brighter star actually covers a larger section of the sky. The size is just a way of representing the brightness.

A map such as figure 1 only gives a snapshot. It shows the stars in the sky at a particular moment and from a particular place. A chart like this is out of date just an hour later, because all the stars will then have moved across the sky. Apps have therefore been made that can provide a celestial map for any time and any place.

The nearest star is the sun. Like all stars, the sun is an enormous ball of glowing, hot gases. The surface is so hot that it emits light and other kinds of radiation. Compared to other stars, the sun is not unusually large and not particularly hot. There are stars that emit far more light and other radiation than the sun does.

When it is really dark, you can see a band of light that is known as the Milky Way. In figure 1, the Milky Way runs from the top left to the bottom right of the map. If you look at the Milky Way through a telescope, you can see that it is made up of countless stars. Those stars seem to be faint because they are so far away, which is why you can't make the individual stars out with the naked eye.

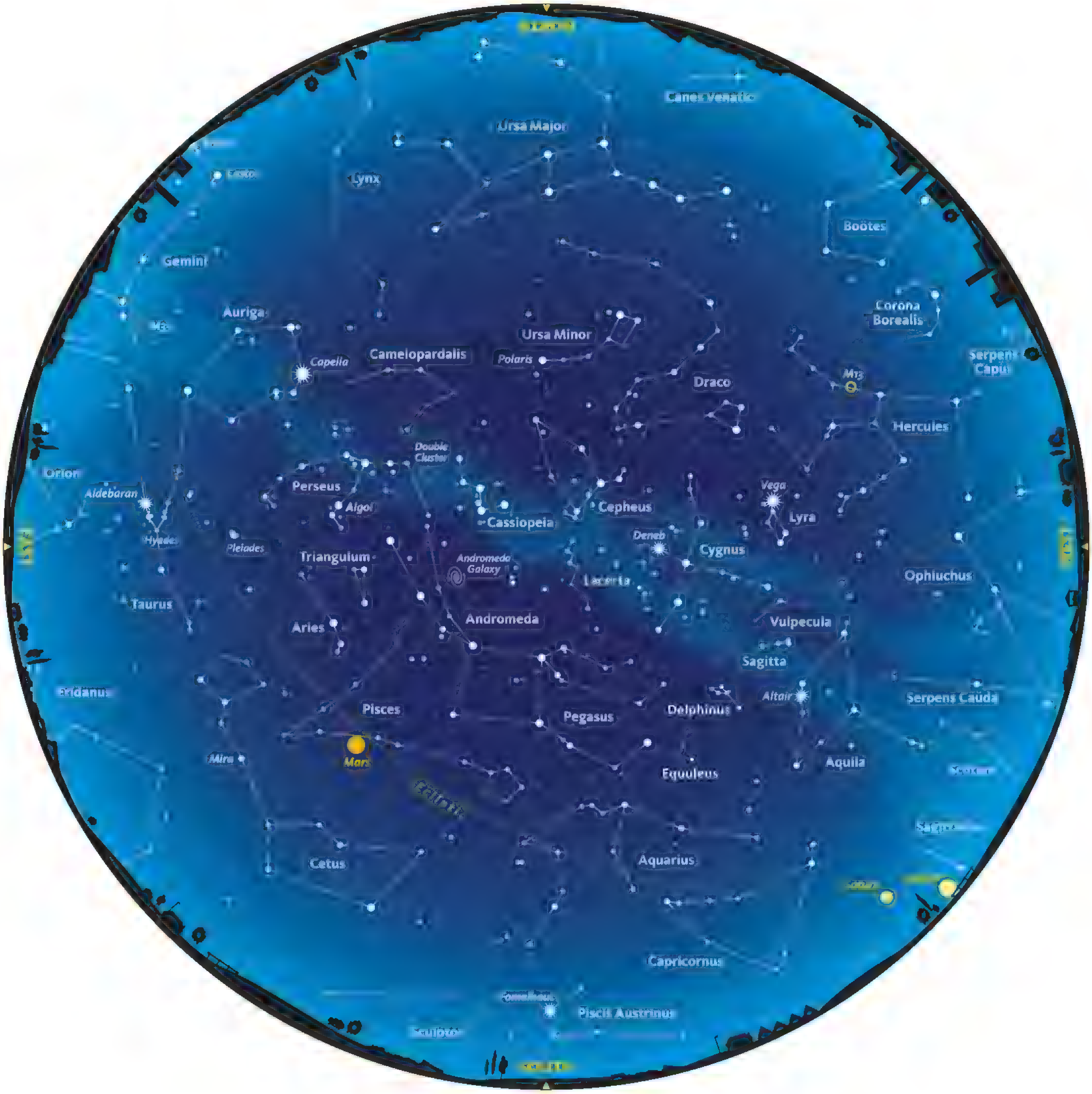


figure 1 The stars in the sky on 15 October 2020 at 23:00, as seen from the Netherlands.

TRIANGULATION IN THE UNIVERSE

Some stars are relatively close to the Earth. Astronomers can determine the distances to those stars through **triangulation**. Figure 2 shows you how that technique works on the Earth's surface. To work out the distance *d* from the ship to the shore, you draw a **baseline** AB of a known length. You then measure the angles ∠α and ∠β. Using those three pieces of information, you can work out the distance *d*.

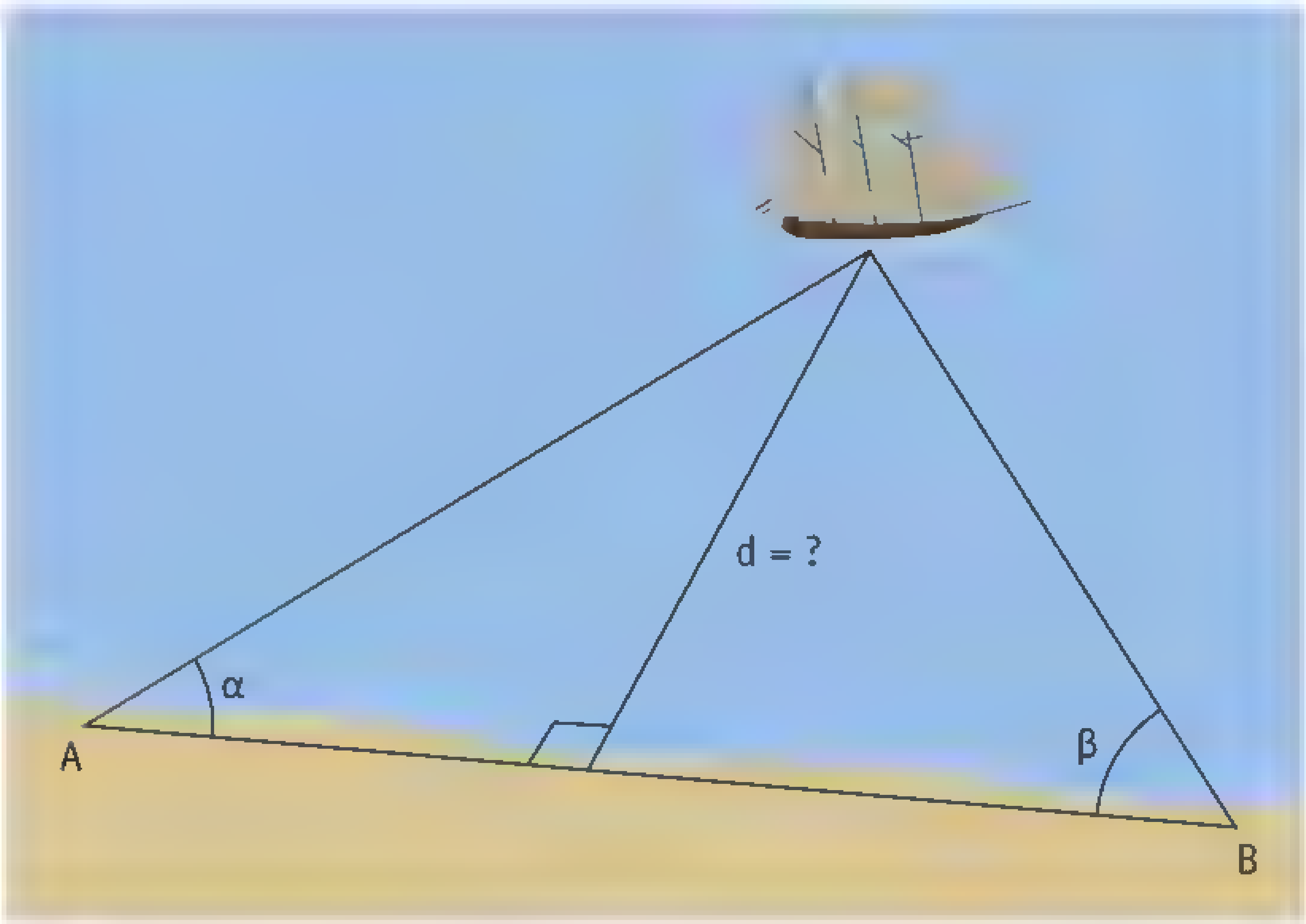


figure 2 This is how you can triangulate the distance to a ship.

Triangulation measurements with stars are more difficult because the distances in the universe are so enormous. It means that you need a very long baseline. Astronomers use the longest baseline they can possibly find: the diameter of the Earth's orbit. They make their first observation in the winter and the second in the summer, for example, when the Earth is on exactly the opposite side of the sun.

Figure 3 shows you how that kind of astronomical triangulation works. The position of the star is measured twice at an interval of six months. The star is then seen to be at a fractionally different angle the second time than it was at first. The bigger the difference between the two angles, the closer the star is to the Earth. Using that measurement data, you can work out the exact distance.

The distance between the two angles is in practice far smaller than in the drawing. But it is not possible to draw it to scale: if you put the Earth and the sun 5 cm away from each other, you'd have to draw the nearest star more than 13 km away. The difference between the two angles is in reality therefore also extremely small, less than $\frac{1}{1000}$ of a degree.

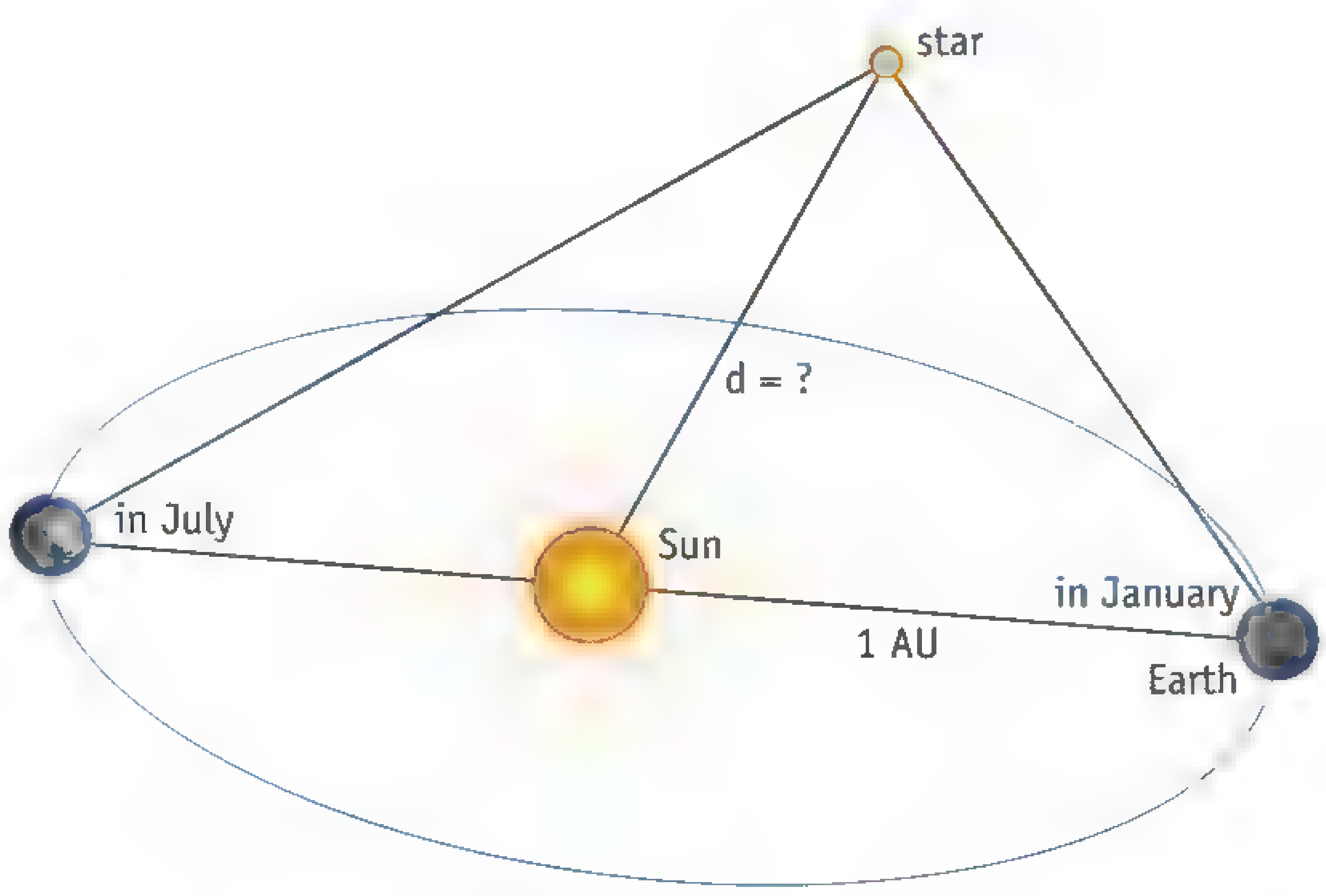


figure 3 A triangulation measurement in the universe (not to scale).

DISTANCES IN LIGHTYEARS

There are not very many stars for which the distances can be triangulated. Most stars are much too far away for that. You need other methods for those stars. To check whether such a method works, astronomers also apply it to stars that they already know the distances for. If the results are the same, that help build up confidence in the new approach.

Over the last two hundred years, astronomers have worked out a whole series of methods for working out distances in the universe. That has let them look further and further into the universe. For distances like these, the AU is not a very useful unit. It is simply too small. So astronomers thought up a new unit, the lightyear (ly).

A lightyear is the distance that light travels in one year in the vacuum of space. Rounded off:

- 1 lightyear = $9.46 \cdot 10^{12}$ km (9.46 trillion km)
- 1 lightyear = $63 \cdot 10^{3}$ AU (63,000 AU)

EXAMPLE EXERCISE 1

The star that is closest to the sun is called Proxima Centauri. The distance between that star and the Earth is 4.24 lightyears.
What is the distance between Proxima Centauri and the Earth in km?

given — the distance between Proxima Centauri and the Earth is 4.24 ly
1 ly (rounded off) is $9.46 \cdot 10^{12}$ km

required — the distance between Proxima Centauri and the Earth in km

working — If 1 ly equals $9.46 \cdot 10^{12}$ km, 4.24 ly equals:
$4.24 \times 9.46 \cdot 10^{12} = 4.01 \cdot 10^{13}$ km

GALAXIES

Telescopes have become better and better over time. They are now able to take pictures of stars and other 'objects' that are much too weak to see with the naked eye (figure 4). Telescopes have also been developed that detect other forms of radiation, such as infrared and ultraviolet radiation. Thanks to these instruments and others, a new picture of the structure of the universe has slowly been built up.

figure 4 The two Keck telescopes on Hawaii have mirrors with a diameter of 10 m.

In that new picture, the sun and all the visible stars are parts of a **galaxy**: a collection of several hundred billion stars with enormous spiral arms. Most of those stars are a long way away from the Earth. They make up the Milky Way, which can be seen as a fuzzy band of light in the sky. Only the closest stars can be seen individually.

Astronomers have discovered that there are lots of other galaxies too. Figure 5 is a nice example: the galaxy M81 in the constellation Ursa Major (or the Great Bear). The system is relatively close to the Earth, at a distance of 'only' twelve million lightyears. M81 is very similar to the galaxy that the sun and the Earth belong to.

figure 5 The galaxy M81. The stars in the foreground belong to 'our' galaxy.

Wherever astronomers look in the universe, they see galaxies. There are many billions of them in total. The galaxies that are furthest away are at distances of billions of lightyears. Of all the huge amount of light that a galaxy like that emits, only a tiny fraction reaches the Earth.

Practice the concepts using the *Flash cards*.

EXTRA EXOPLANETS

The solar system is not unique in the universe. There are lots of other stars that have one or more planets going round them. Planets orbiting stars other than the sun are called exoplanets. The Greek word 'exo' means *outside*; exoplanets are called that because they are planets outside our solar system. The first exoplanet was discovered in 1992. At the end of 2020, more than four thousand exoplanets were known.

Astronomers are not able to see exoplanets directly. A planet does not reflect enough light to the Earth for that. Instead, astronomers look at the light of the star that the exoplanet is going round. Small changes in that light can betray the presence of one or more exoplanets. Various methods have been thought up for detecting these exoplanets.

In the transit method, a telescope records the amount of light given off by a star. If an exoplanet moves in front of the star (this is known as a 'transit'), there will be a small 'dip' in the amount of light (figure 6). One orbital period later, there will be a second dip. And another orbit later, there will be a third. For astronomers, a sequence of small dips is proof that an exoplanet is orbiting the star.

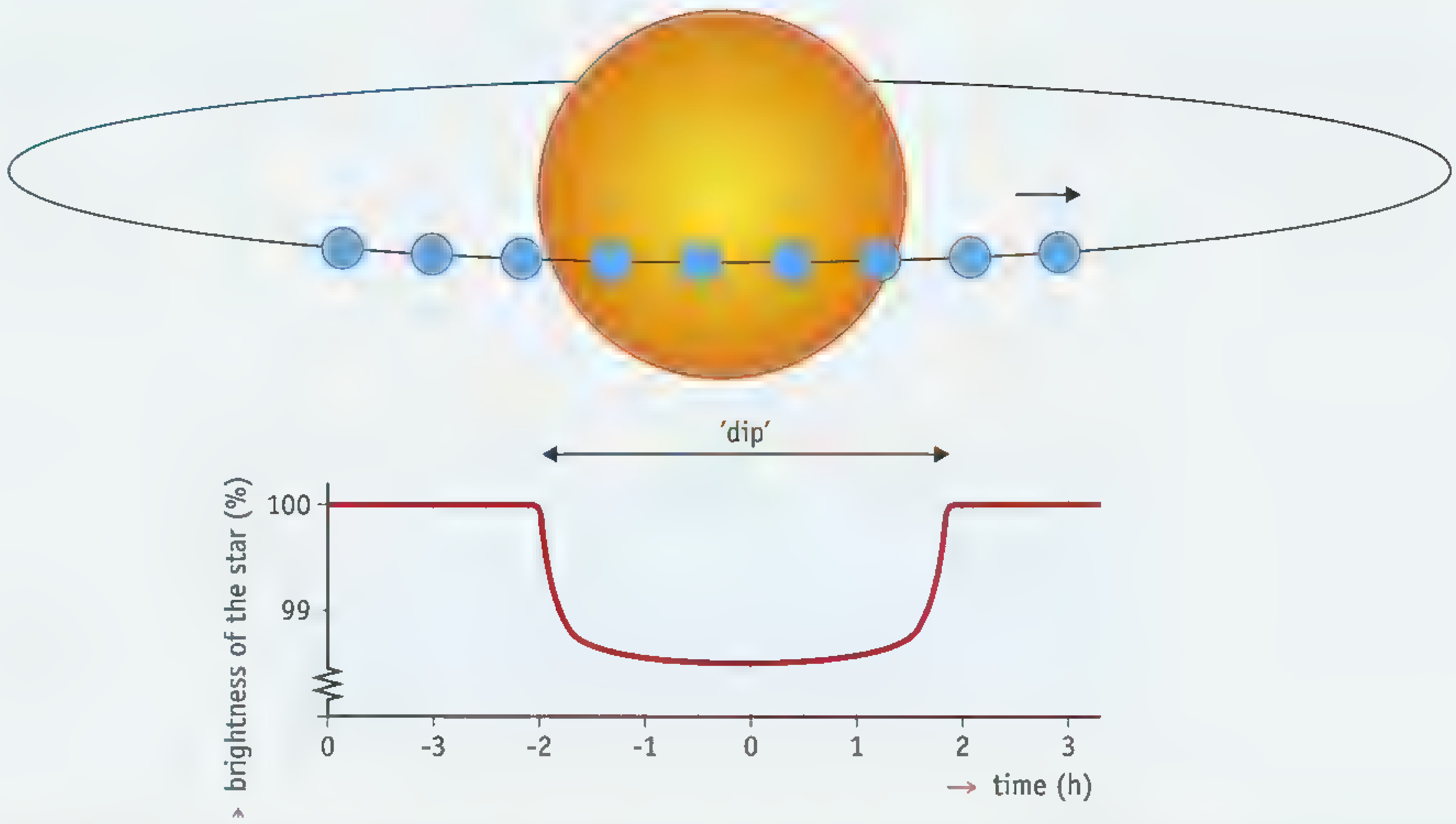


figure 6 When a planet moves in front of a star, that star will temporarily be less bright.

COURSE MATERIAL

1

Complete.

a A star is an enormous ball of glowing, hot .... The surface is so hot that it emits light and other kinds of ....

b If a star is relatively .... the Earth, astronomers can determine the distance by ....

c Astronomers use the longest .... they can possibly find for their measurements: the .... of the Earth's orbit.

d A .... (rounded off) is 9.45 trillion km, which is the .... that light travels in one year in the vacuum of space.

e The .... that the solar system is part of (the Milky Way) consists of hundreds of .... of stars.

2

Say whether each of the statements is true or false.

a	The sun is a star that is much close to the Earth than the other stars.	*true / false*
b	Compared to most other stars, the sun is particularly large and hot.	*true / false*
c	The Milky Way is a constellation with various strikingly bright stars.	*true / false*
d	The AU is not a suitable unit for the distances between galaxies.	*true / false*
e	12 million lightyears is 'relatively close by' for a galaxy.	*true / false*

IN PRACTICE

3

Have a look at figure 1.

- a What constellation was the planet Mars in at the time shown?
- b Which planet is about to set in the southwest?
- c Which constellation of the zodiac is just rising in the northeast?
- d In which direction will you find the constellation Ursa Major, according to the chart?
- e What is the name of the band of light that you can see running from northeast to southwest?

★ 4

Figure 7 shows the constellation Ursa Minor as it was at 23:00 on 15 October 2020. Compare figure 7 against figure 1. Four other positions (A to D) are also given in figure 7.

- a Which position would Ursa Minor have been in on 16 October 2020 at 02:00?
- b Write down the times for the other three positions.

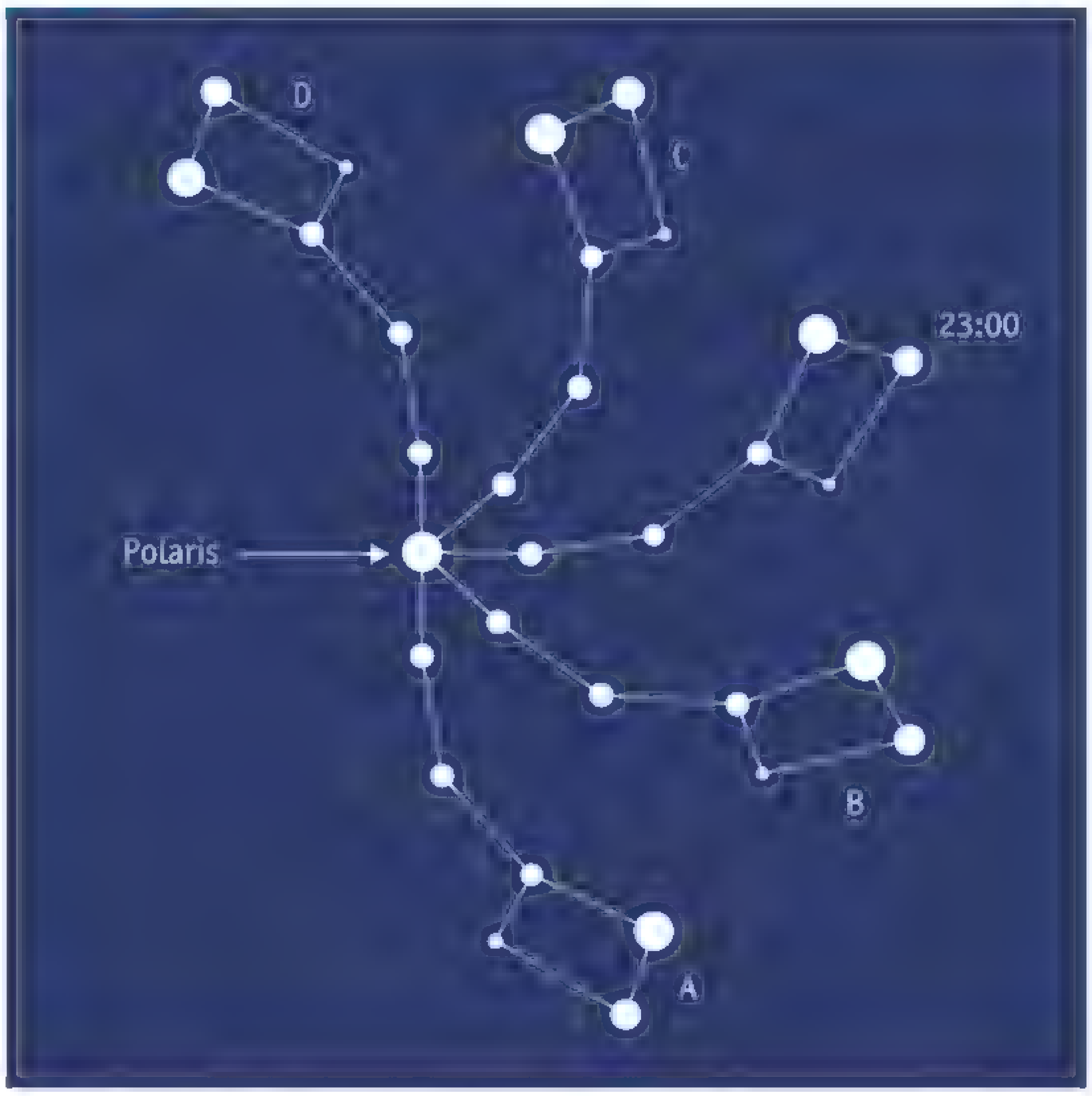


figure 7 How does Ursa Minor rotate?

5

Figure 8 is a drawing showing you how an astronomical triangulation is done in practice. Astronomers take photographs of star X twice, at an interval of six months. They then measure how far the star has shifted on the photographs with respect to the 'background stars' that are also on the photograph. That lets them determine the difference between the two angles defining where the star is in the sky.

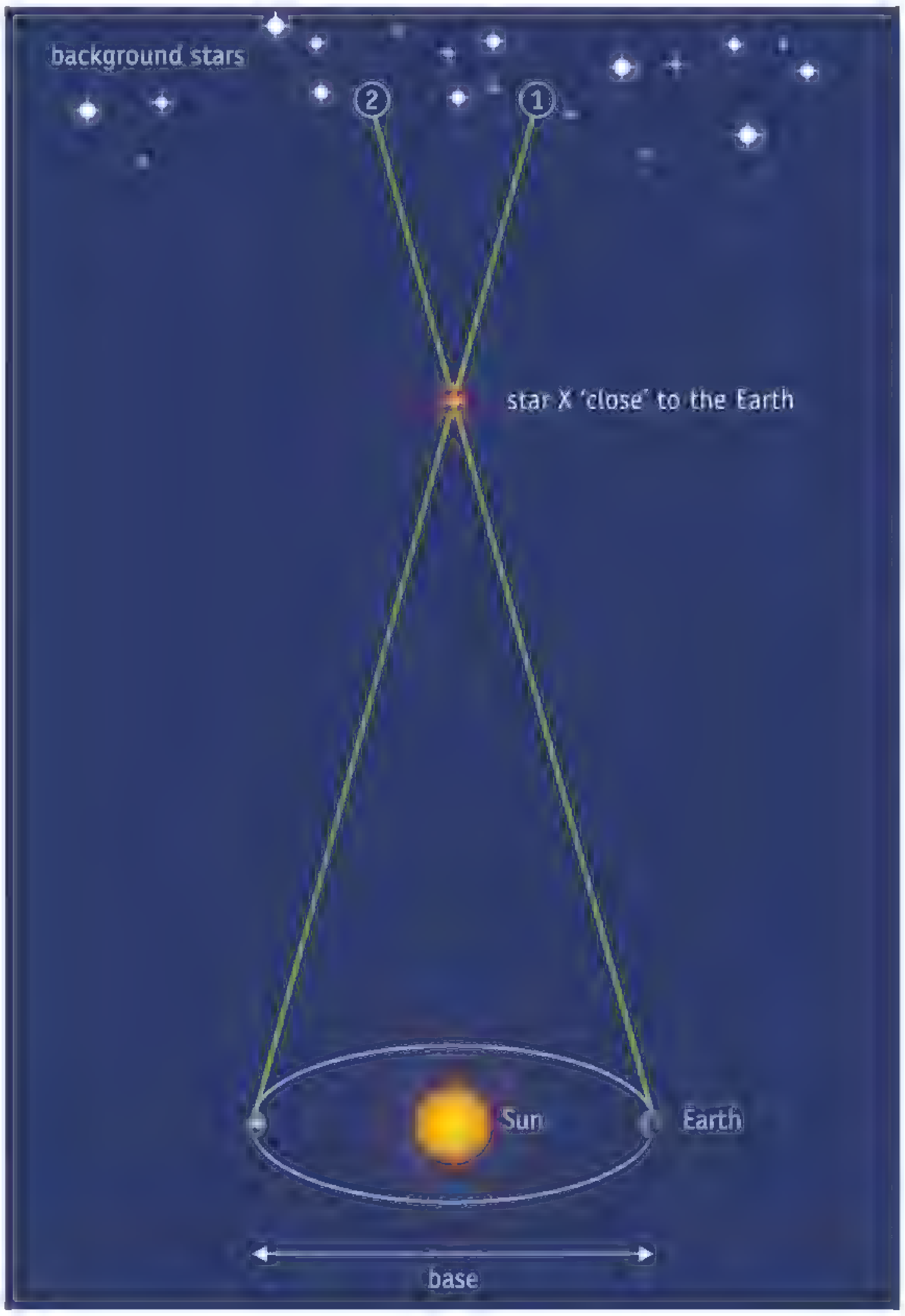
a How big is the baseline that astronomers can use in this measurement (in AU and in km)?

b On 15 February, you can see star X in direction 1 against the background stars. On what date (roughly) can the star be seen in the sky in direction 2?

c Why don't the 'background stars' in the photographs seem to have moved?

d Suppose that star X seems to have shifted a lot more than star Y. What does that let you conclude about their distances from the Earth?

figure 8 This is how you determine the difference between the two angles (not to scale).



1

On photo 1 you can see star X to the right of the background stars.

2

On photo 2 you can see star X to the left of the background stars.

6 Figure 9 shows you two images of a small piece of the sky. The images were made at an interval of six months. The piece of sky shown is 1.5 by 1.5 arcseconds. The arcsecond is a unit that is $\frac{1}{3600}$ of a degree. If you were to divide the space between two degree markers on your protractor into 3600 equal zones, each of those would be 1 arcsecond.

a How can you tell that the same piece of the sky is being viewed on both images?

b First you have to determine the scale of the images. Complete:

Each picture measures .... by .... cm.

A distance of .... cm is therefore equivalent to an angle of 1.5 arcseconds.

That means that a distance of 1 cm is equivalent to .... arcseconds.

c Measure how far the red star at the bottom right has shifted over six months. Complete:

The star on the right-hand picture has shifted .... cm compared to the left-hand picture.

d Convert the shift into arcseconds (using the scale factor from Exercise 6b). Complete:

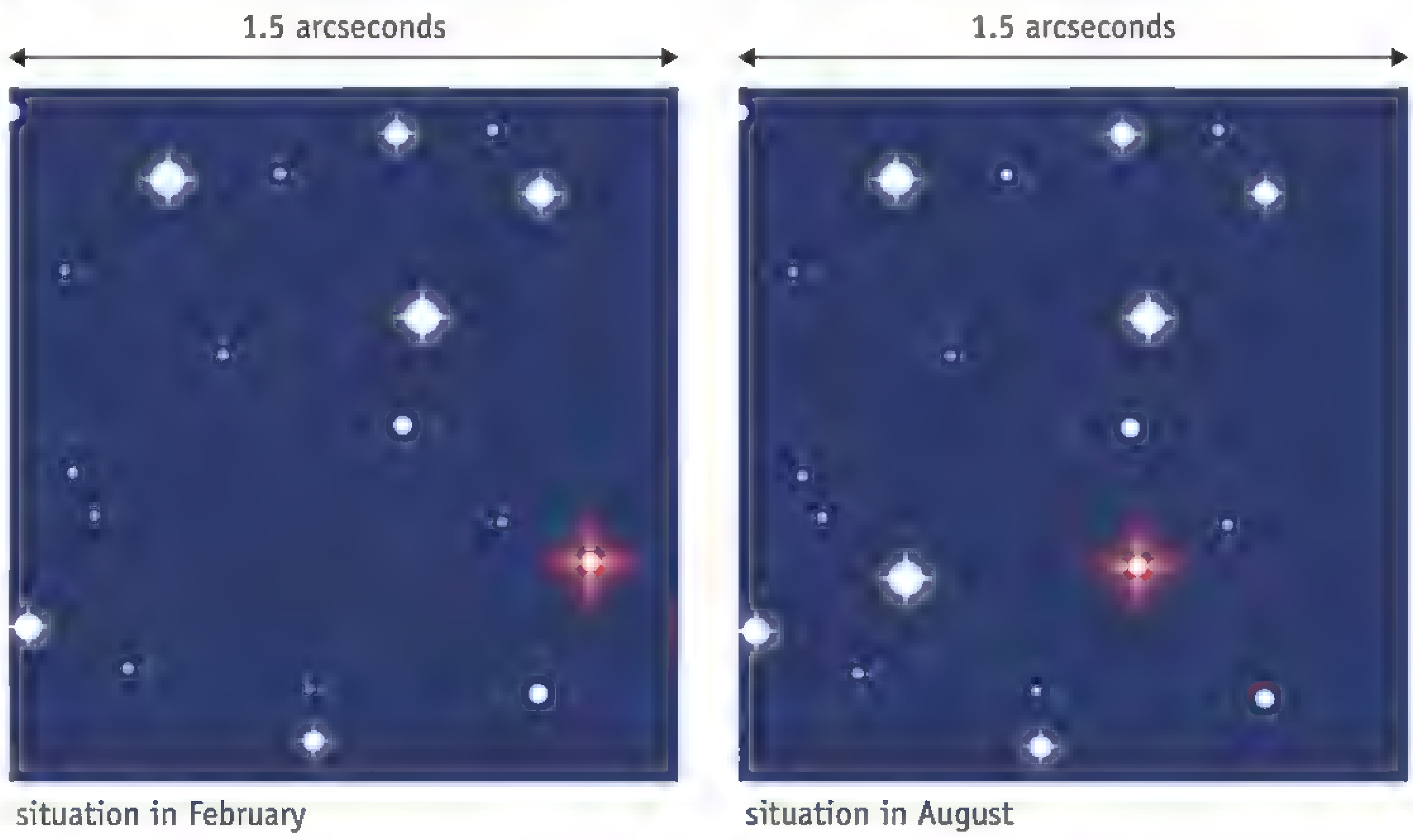
The shift of the star, after converting, is: .... arcseconds.

e You can now calculate the distance in lightyears using the following calculation rule:

$$\text{distance in lightyears} = \frac{6.52}{\text{shift in arcseconds}}$$

Show all your calculation steps.

figure 9 Two pictures of the same piece of the sky taken six months apart.



situation in February situation in August

7

Figure 10 shows you the constellation of Orion and the names of its four brightest stars, Rigel, Betelgeuse, Bellatrix and Alnilam. Natalie reads on an astronomy website that astronomers have recently recalculated the distances to these stars. The new values are given in table 1.

Show that the following statements match the data given in table 1.

- **a** Rigel is $8.2 \cdot 10^{15}$ km from the Earth.
- **b** Betelgeuse is 31 million AU away from the Earth.
- **c** Alnilam looks equally as bright as Bellatrix, but radiates much more light in reality.
- **d** The stars of a constellation do not really belong together – it just looks like that.

table 1 Data for the four brightest stars in Orion.

star	distance to the Earth (ly)
Rigel	863
Betelgeuse	498
Bellatrix	252
Alnilam	1976

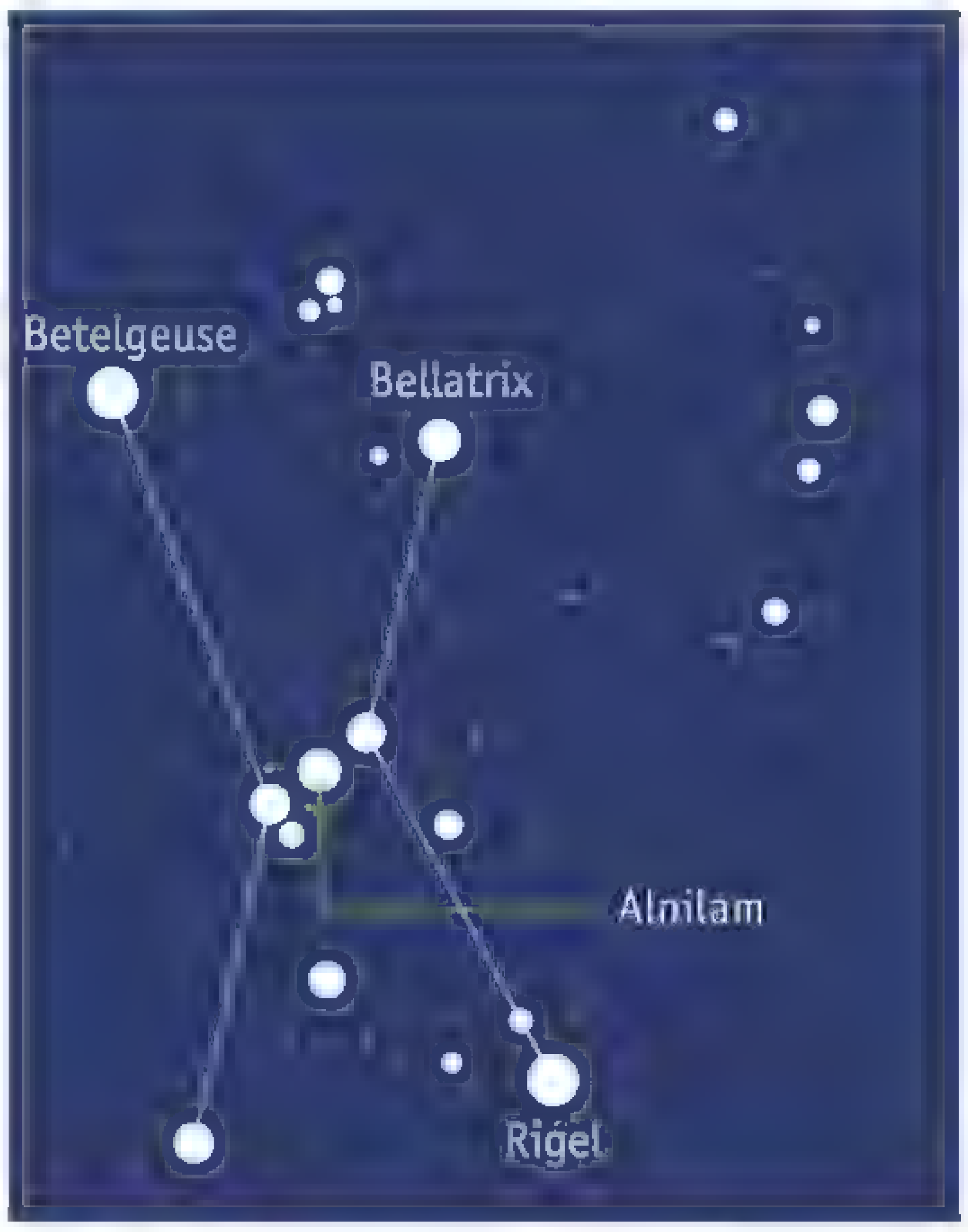


figure 10 The constellation of Orion.

8

In Exercise 8 of Section 2, Aisha and Simone laid out a model of the solar system on a football pitch. They were using a distance of 10 m for 1 AU. Now they are wondering whether they could also give Proxima Centauri a place in their model.

- **a** How far is Proxima Centauri from the Earth (in lightyears).
- **b** Convert that distance from ly into AU.
- **c** Aisha and Simone are using a softball to represent the sun to scale. For Proxima Centauri, they could use a marble; this is a much small star than the sun.
  At what distance from the softball would they then need to place the marble? Show all your calculation steps.

★ 9

You can find some wonderful photographs of galaxies on the internet. Use the following search terms, for example: *NASA – galaxy – Hubble*. Make sure that you're looking at a genuine astronomical photograph and not an artist's impression or a collage of different images.

Pick one such galaxy to find out more information about it. Examples:

- Where in the sky is that galaxy located?
- What type of galaxy is it?
- How far is that galaxy from the Earth?
- What is its diameter (in lightyears)?
- How is it moving with respect to the Earth?
- What makes the galaxy unusual or striking?

Write up what you have found as a short essay of two A4 pages, with pictures.

Test what you know with *Test yourself*.

EXTRA EXOPLANETS

10 The space telescope Kepler was operational from 2009 to 2018. This telescope looked for exoplanets by systematically measuring the brightnesses of about half a million stars. That information was turned into light curves, graphs plotting the brightness of a star against time.

Have a look at the light curve of the star HAT-P-7 in figure 11.

- **a** How can you see that a planet is moving in front of the star at regular intervals?
- **b** How big is the reduction in the amount of light emitted by the star (as a percentage)?
- **c** How can you tell that the planet is only small compared to the star it is orbiting?
- **d** Read off from the light curve what the orbital period of this planet is.
- **e** What does the orbital period tell you about the distance between the exoplanet and the star it is orbiting?

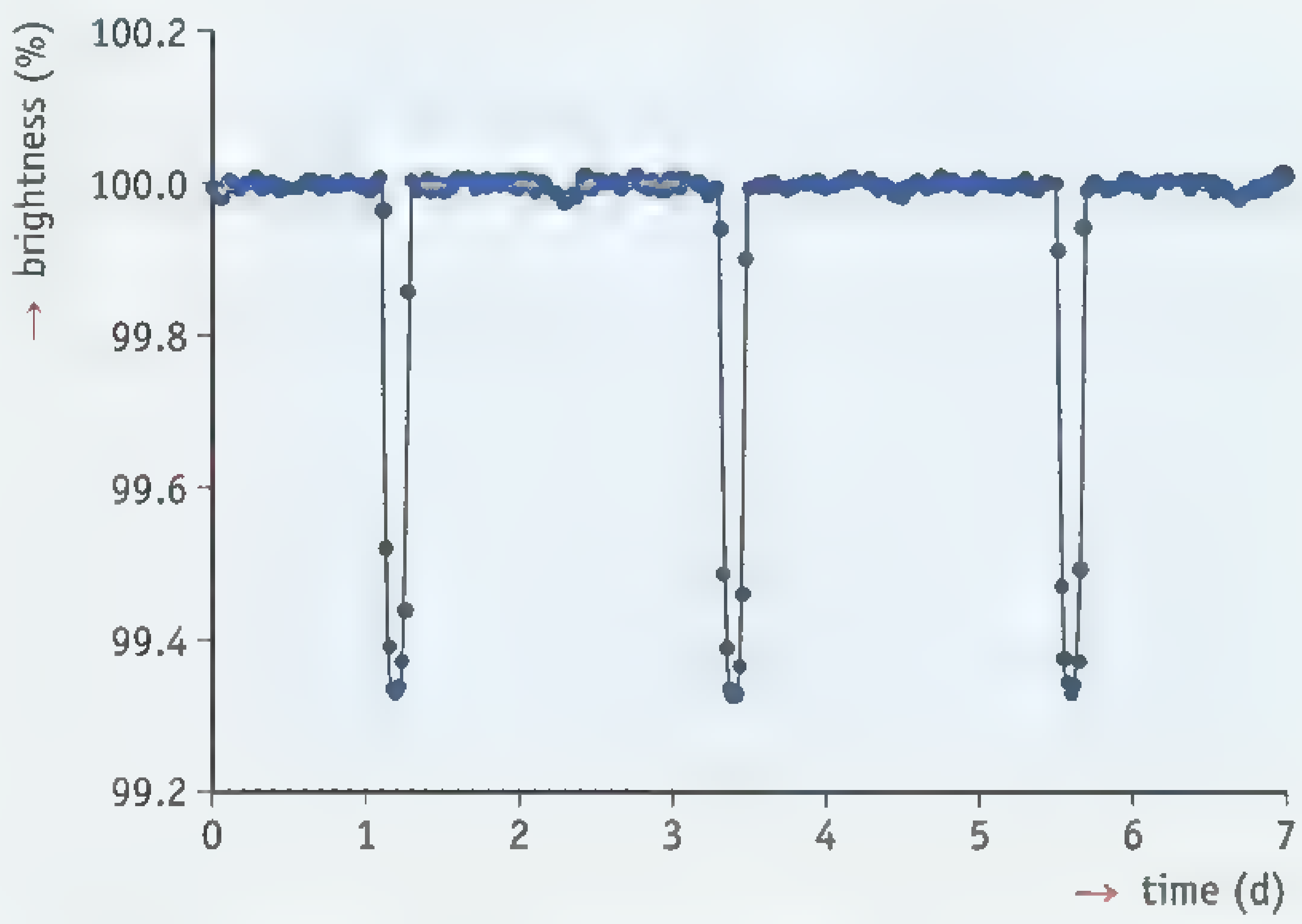


figure 11 The light curve of the star HAT-P-7.

11 The transit method only works if you are looking at the planet's orbit directly 'side on' from the Earth. Planets with orbits at any other angle cannot be found using this method. Use a drawing to show why a planet in that situation will not create a dip in the star's light.

12 The Kepler space telescope has found planets in all kinds of sizes, from a little smaller than the Earth to even bigger than Jupiter. But astronomers also assume that Kepler has often missed smaller planets, the size of Mars or Mercury.

Explain why a small planet such as Mars is harder to find than a larger planet.

Experiments

EXPERIMENT 1 MAKING A SUNDIAL

100 minutes

Introduction

People have been measuring time since Antiquity by looking at the positions of the sun and moon. The Gregorian calendar, which is now used all over the world, is based on the position of the sun. The Muslim and Jewish calendars are based on the phases of the moon.
You can also use the position of the sun to determine how late in the day it is. Various types of sundials have been invented for doing that (figure 1). You will learn more about that in this experiment.

figure 1 One of the three types of sundial.

Goal

In this experiment, you will first investigate what kinds of sundials there are. You will then pick one type of sundial to make yourself.

Requirements

For this experiment, you have to think up for yourself what equipment you will need.

Doing the experiment and writing it up

Before starting

- Search for information on the internet about various types of sundials and how you can make them. Suitable search terms would be things like *making a sundial*.
  Search for answers to the following questions:
  – What are the three most widely used types of sundial?
  – What are the components in every type of sundial?
  – What direction does the sundial have to face?
  – What angle should the part casting the shadow be at?
  – What is a 'time correction table' (using the 'equation of time') and how do you use one?
  Write up the answers as a short report (about two A4 pages).
- The reports will be discussed in the lesson. Check the information that you have collected together and make improvements to it if necessary.

Making a sundial

- Choose one of the various types of sundial to make yourself. Make a practical design that you can easily put together yourself. It may be an attractive design, but that isn't a requirement.
- Find a suitable location for your sundial and set it up carefully, facing in the correct direction.
- Read off the time at three different moments during the day. Use the time correction table to work out the correct time. Check the official time at that moment too (read it off your phone).

1 Write down the following in table 1 for each observation: (1) the time that you read off, without a correction; (2) the time after correction using the time correction table; (3) the official time.

table 1 Three measurements of time.

observation	time as read (without correction)	time as read (with correction)	official time
1			
2			
3			

2 Compare the times that you read off.
What is your conclusion: how accurately can you determine the time with your sundial?

....

....

....

EXPERIMENT 2 MAKING A MODEL OF THE SOLAR SYSTEM

20 minutes

Introduction

The distances in the solar system are huge. It is difficult to get a clear picture of how far apart the sun and the planets all are from each other. A good way of getting an idea of this is to use a scale model.

Goal

In this experiment, you will be making a model of the solar system. In that model, you will be representing the distances between the sun and the planets at a scale of 1:15,000,000,000. In other words: 1 m in the model will be 0.1 AU ($15 \cdot 10^6$ km) in reality.

Requirements

- ☐ a large open space (sports field, school yard, large lawn)
- ☐ softball
- ☐ 6 marker cones or similar
- ☐ measuring tape (1 m)
- ☐ cord (10 m)

Doing the experiment and writing it up

- To measure off the various distances, you will use a ten-metre cord in which a knot has been tied every metre.
- The softball represents the sun, at the same scale as your model. Put it down at the edge of the sports field (or school yard or lawn).
- The Earth moves in an orbit that is on average 1 AU from the sun. In your model, that is 10 m. Measure that distance out. Mark the Earth's orbit with one of the marker cones (figure 2).

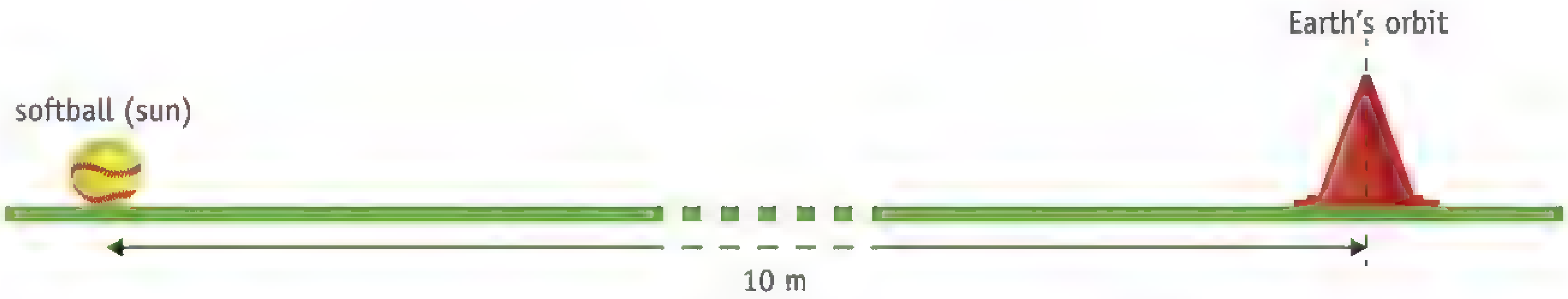


figure 2 The sun and the Earth's orbit in the model of the solar system.

1 Calculate how big the distances have to be between the other planets and the sun in your model. Write the results down in table 2.

table 2 Orbital data for the planets.

planet	average distance to the sun (AU)	distance in your scale model (m)
Mercury	0.39	
Venus	0.73	
Earth	1.0	10
Mars	1.5	
Jupiter	5.2	
Saturn	9.6	
Uranus	19	
Neptune	30	

- Measure out the distances that the planets Mercury, Venus, Mars, Jupiter and Saturn orbit the sun at. Put out a marker each time to show where the orbit of the planet is.

Report

- Make a video clip on your smartphone presenting your model. Start at the softball that represents the sun. First go to Mercury, then on to Venus, and so forth. Say which marker represents which planet, or use a sign to show it.
- To finish your clip, show (roughly) where the orbits of Uranus and Neptune would be if you had included those two planets in your model as well.

EXPERIMENT 3 WORKING WITH A STAR CHART

20 minutes

Introduction

To locate stars, planets and other heavenly bodies, you absolutely have to have a star chart. There are apps and websites that can provide a celestial map for any time and any place. In this exercise, you will be getting to know Stellarium, a free online star map for your smartphone or computer.

Goal

In this experiment, you will be learning how to find stars, constellations and planets in the sky using an online star chart.

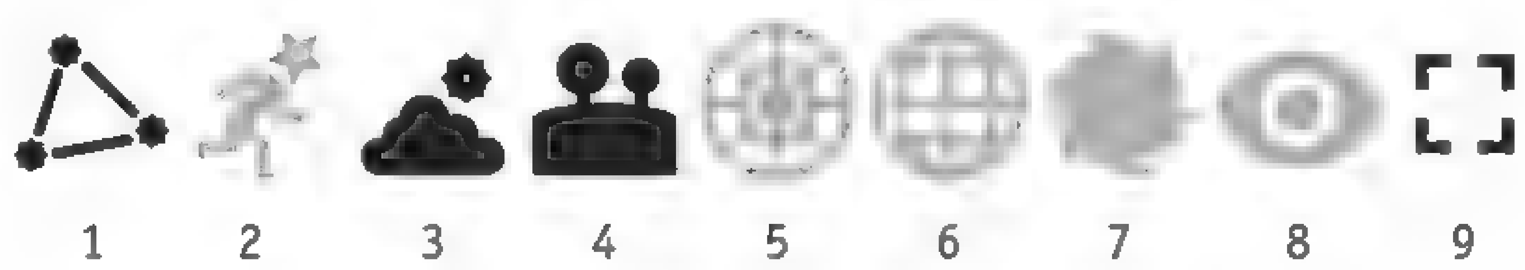
Requirements

☐ computer, tablet or smartphone

Implementation

Preparation

- Start the browser on your computer or tablet. Go to the website https://stellarium-web.org.
- Select **Allow access to my location** when Stellarium asks.
- Click **View Settings** at the top left. Tick all the boxes except **Meridian Line**.
- A menu with nine symbols will then appear at the bottom of your screen (figure 3).
- Enable symbols 1, 3, 4 and 9 (= white) and leave the other symbols disabled (= grey).
- Click the box at the bottom right of the screen showing the date and time. Set the date to 21 March 2023 (2023-03-21) and the time to 20:00:00.
- Click the pause button ⏸ to stop the clock.
- Drag the map until you are looking directly due south (S).



1 Constellations
2 Constellations Art
3 Atmosphere
4 Landscape
5 Azimuthal Grid
6 Equatorial Grid
7 Deep Sky Object
8 Night Mode
9 Full Screen

figure 3 The selection menu in Stellarium.

1 Which zodiacal constellations are in the sky at that moment (from east to west)? Use the list in figure 4. Tip: look along the ecliptic.

....

....

figure 4 Constellations.

The names of the zodiacal constellations
The names of the zodiacal constellations and their meanings are given below. Stellarium uses the Latin names (which is normal for the zodiac in particular in English).

Aries – the ram	*Libra* – the scales
Taurus – the bull	*Scorpius* – the scorpion
Gemini – the twins	*Sagittarius* – the archer
Cancer – the crab	*Capricorn* – the goat
Leo – the lion	*Aquarius* – the water carrier
Virgo – the maiden	*Pisces* – the fishes

2 Which four planets are in the sky at that time (from east to west)?

....

3 Which two zodiacal constellations is Mars between at that time?

....

4 What compass direction do you need to look in to find Venus in the sky?

....

5 Is the constellation of Orion also visible at that time, and if so where?

....

- Drag the map until you are looking directly due north (N).

6 Click the Pole Star in the constellation of Ursa Minor.
Stellarium uses the Latin name for the Pole Star. What is it?

....

7 Draw what Ursa Minor looks like in the sky at that moment.

- Click the box at the bottom right of the screen showing the date and time. Use the arrow above the number of hours to move the clock on to 02:00:00. The date will change to 22 March 2023 (2023-03-22) as you do so.

8 Draw what Ursa Minor now looks like in the sky, at 02:00.

- Drag the map until you are looking directly due south (S) again.

9 Which zodiacal constellations have risen during the intervening six hours?

....

....

10 Which planets have set in the west between 20:00 and 02:00?

....

11 How has the position of Mars changed over the intervening six hours?

....

....

- Click the box at the bottom right of the screen showing the date and time. Use the arrows above and below the time to see how the constellation of Orion drops below the horizon.

12 Orion's Belt is made up of three bright stars in a line close together.
When does the belt disappear below the horizon, roughly?

....

- For observing the actual sky, the best thing to do is install the Stellarium app on your mobile. That means that you will always have a star chart to hand. Constellations, unusual stars and planets can then always be found quickly.

Finally! The day you knew would come sooner or later has arrived. You're delighted to be able to leave, yet at the same time seriously scared about what's ahead of you. You are sitting firmly strapped into your seat in the spaceship. The countdown begins. "Three, two, one... lift off!" And then you shoot off, up and away from Planet Earth, ready for a trip to Mars that is going to take you at least six months.

The journey

It is 1 July 2037. A couple of years ago, you were selected as one of the first group of pioneers who will be living on Mars, the Red Planet. You were selected by the international venture *Life on Mars*, which was founded after the World Peace Treaty of 2030. The participants are the former space exploration organizations NASA and ESA, the Chinese government and Elon Musk's corporations. Those organizations have sent unmanned rovers to Mars that have been busy for years, preparing for manned flights. They concluded that cooperating was better than competing for this complex and expensive venture.

You have followed an intensive training programme over the last few years. It consisted of a lot of technical and medical theory as well as practical lessons. You may also perhaps have been trained in psychology, because being able to deal calmly with other people is essential if you're going to be cooped up with them for a long time in a small space. You've also done a lot of sport. You'll have to do a lot of sports exercises every day during the journey. That's because you're weightless in space, just floating, which means that your body won't have to work so hard and you could lose muscle mass and bone mass. To compensate for that, you've got to do a lot of sport. When you arrive on Mars, you want still to be healthy (of course), because there are a lot of things waiting for you to do...

A soft landing?

Mars takes 1.88 Earth years to orbit the sun. That is the most important factor why the distance between Mars and the Earth varies over time between 54.6 and 401 million kilometres. A trip to Mars is only possible once every 26 months, when the two planets are close enough together. There is then a window of about three months during which astronauts and equipment can leave. People who travel to Mars will have to stay there for more than an Earth year before a trip back to their home planet becomes possible (table 1).

"By 2050, I plan to have sent a million people to Mars."
Elon Musk

table 1 Possible departure dates for equipment (which is sent earlier) and astronauts for the manned mission in 2037.

	first possible date	last possible date
departure of equipment transports from Earth	1 April 2035	30 August 2035
departure of astronauts from Earth	1 July 2037	30 September 2037
return of astronauts from Mars	15 April 2039	15 January 2040

It is January 2038. After many months, your spaceship reaches the Red Planet (figure 1). The journey has gone smoothly so far, but now it gets really exciting! Will everyone and everything make it through the landing? You're now travelling at a speed of 21,000 km/h. Rockets are now fired to reduce the approach speed enormously. You circle the planet for a few weeks more, braking further. Braking and landing is not easy because the atmosphere on Mars is much thinner than on Earth. The atmospheric pressure on Mars is more than a hundred times lower, so there are fewer molecules in the air – and the smaller the number of molecules, the less the air can decelerate objects. That is why there is a colossal heat-resistant parachute on board for the landing. Now it's time to deploy it and then...

Oxygen

Everyone has survived the impact of landing. The mood on board is fantastic! After all that time in the spaceship, everyone wants to get outside for the first walks. Everybody wriggles quickly into their special spacesuits, which are fitted with oxygen cylinders (figure 2). Because even breathing isn't easy on Mars. The planet's atmosphere consists almost entirely of carbon dioxide with just 0.1% oxygen.

You were able to breathe in the spaceship because electricity from solar panels was used to keep supplying fresh oxygen by splitting the water you had on board. And algae made sure that the carbon dioxide you exhaled was converted back into oxygen. One of your first tasks on Mars is locating water that can be split up by electrolysis, so that you can keep breathing. It's not as if there are rivers flowing and there are no oceans either. There is water, but it is below ground and it is frozen solid. You will have to hack it loose and collect it up. Once it has been thawed, you can drink it. Electricity can be used to split water up into oxygen and hydrogen. Those two gases are collected separately: hydrogen can be used as a fuel and oxygen is for breathing.

When you're outside, you always have to wear a spacesuit. It protects you against harmful radiation from space and from the sun. On Earth, a gas called ozone is always being produced in the atmosphere from oxygen. Ozone makes sure that the radiation is unable to penetrate the Earth's atmosphere, but it's a constant threat on Mars.

Mars Utopia Planitia Station

There's not much time to recover from the journey. You have to start building things – quickly! You very much want a different place to stay than the cramped spaceship you've been cooped up in for months now, along with everyone else. The *Life on Mars* equipment missions of 2035 dropped construction packs and tools at the landing site. These are what you are going to be using to build *Mars Utopia Planitia Station*.

It is cold on Mars. Because the planet is further from the sun than the Earth is, it only gets half as much sunlight. And because Mars has such as rarefied atmosphere, that heat is not retained at night. In full sunlight, the temperature gets

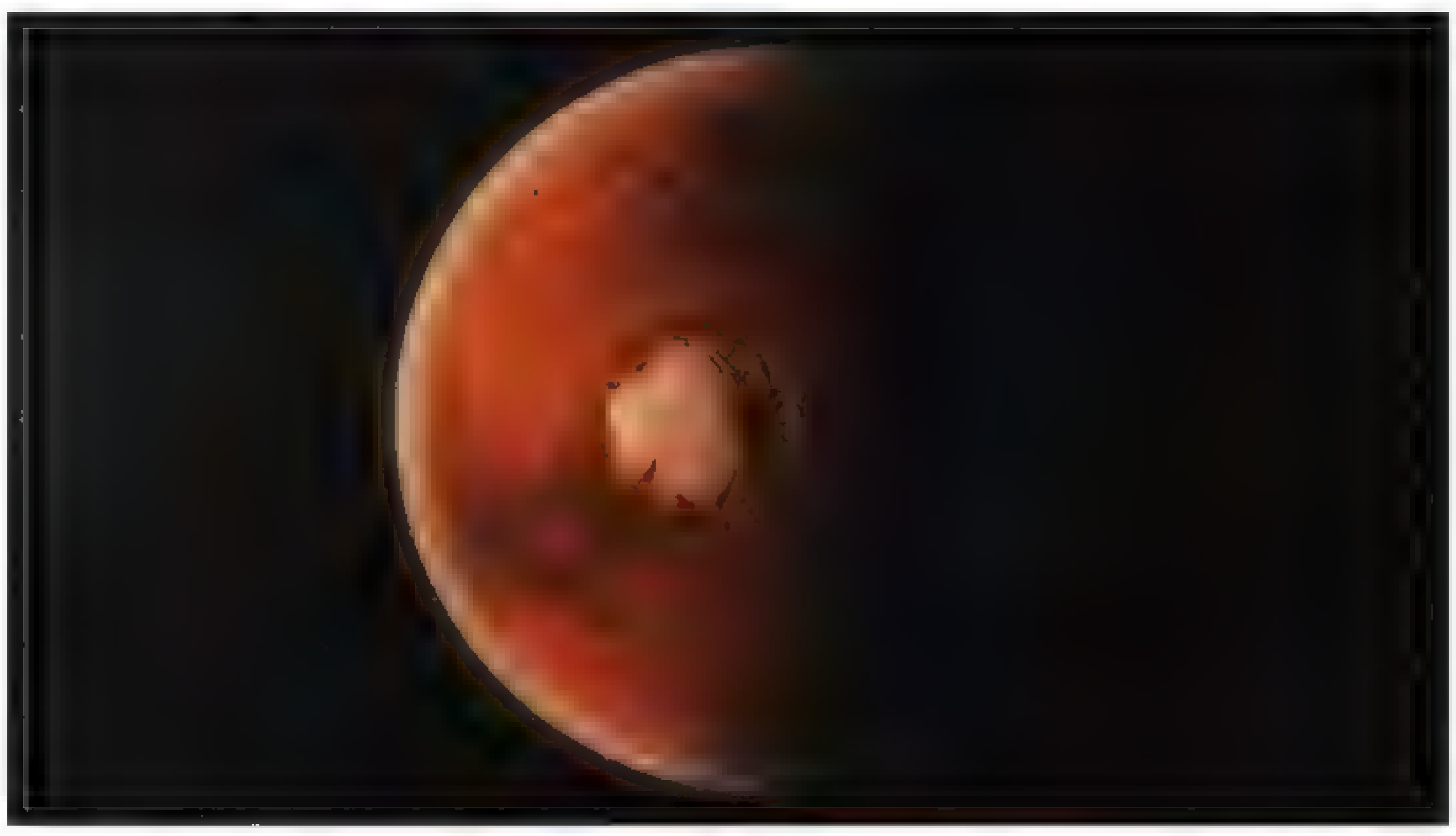


figure 1 You're getting closer and closer to Mars and you can see how thin its atmosphere is.

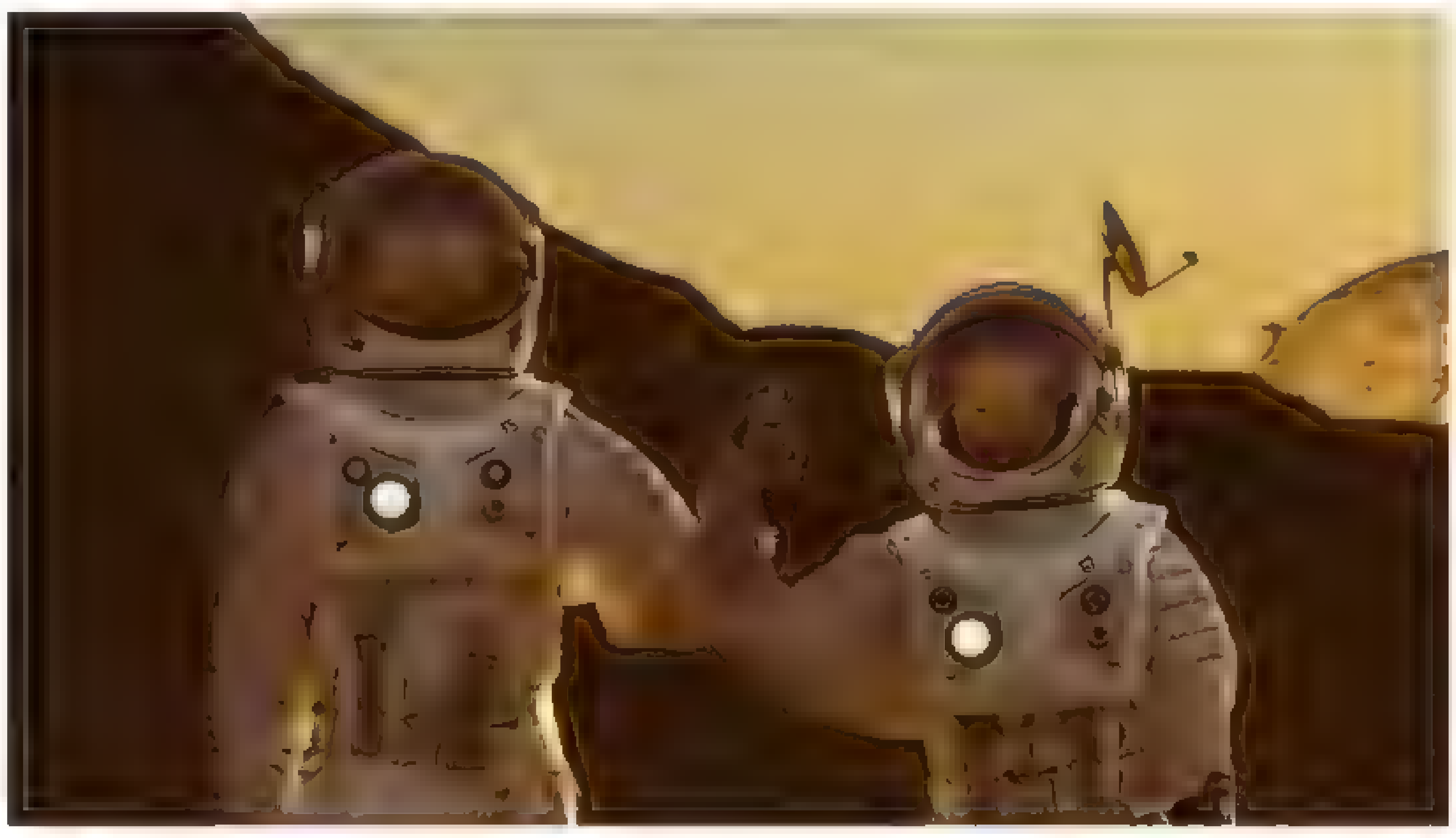


figure 2 A walk on Mars in a spacesuit.

up to a little above 0 °C. At night it freezes right down to −80 to −90 °C. Fortunately, there is enough sun for solar panels to work and generate the energy needed.

figure 3 Design for a greenhouse for food crops on Mars.

The conditions on Mars are not very human-friendly. They also mean that it is impossible for plant life, so your new accommodation is going to include building a large greenhouse where the seeds that were brought with you can germinate and let you grow food crops (figure 3). You will definitely all enjoy the first harvest!

When can you go to Mars?

That story sounds like science fiction, but it isn't – not entirely. NASA, ESA, the Chinese authorities and Elon Musk have already been working together for some time on preparing for manned flights to Mars. Dates have been worked out when the first astronauts could depart for the Red Planet, but those plans are also being pushed back regularly. A trip to Mars is complex and expensive in all kinds of ways. It is really only a question of when the first mission, currently planned for 2037, will be postponed again.

Science fiction plays a bigger role in developing plans for space travel than you might have thought: the genre is a major source of inspiration and ideas for scientists and engineers who are working on the spacecraft of the future.

figure 4 In 1865 and 1870, Jules Verne wrote two science fiction stories about journeys to the moon. They appeared in English as From Earth to the Moon and Round the Moon. A hundred years later, it became reality.

figure 5 *Reaching for the stars.*

ASTRONOMY FOR ALL

It doesn't make much difference where you live: there are young people all over the world who dream of a future as an astronaut. Take Sepideh Hooshyar, for instance, the daughter of a poor widow in Iran (figure 5). At home, she saw clips of Anousheh Ansari, the first woman space tourist, who was on a launch to the International Space Station (ISS) in 2006. Sepideh was lucky enough to be able to join a club of young people who studied the night skies. She had lessons about astronomy from a man in the village who loved the subject. Despite not having much money, one thing led to another and people gave her the opportunity to study. Sepideh did not become an astronaut in the end, but she is an astronomer. A lovely film has been made about her life, *Sepideh, reaching for the stars* (2013). There are also astronomical societies in the Netherlands. The Young People's Astronomy Group is the astronomical society for young people up to age 21. It has branches throughout the Netherlands that organize various activities and camps. You can study the planets and stars there.

After: www.sterrenkunde.nl/jwg

EXERCISES

1 The Martian atmosphere is different from Earth's.

a Which statement is correct?

- ○ A The Martian atmosphere contains fewer molecules than the Earth's.
- ○ B The Martian atmosphere contains the same number of molecules as the Earth's.
- ○ C The Martian atmosphere contains more molecules than the Earth's.

b Which statement is correct?

- ○ A The Martian atmosphere contains a relatively low amount of carbon dioxide compared to the Earth's.
- ○ B The Martian atmosphere contains the same relative amount of carbon dioxide as the Earth's.
- ○ C The Martian atmosphere contains a relatively high amount of carbon dioxide compared to the Earth's.

c Explain why you need to wear a spacesuit when walking around outside on Mars.

2 This story is about a space mission to Mars in the year 2037.

a What is the first possible date on which astronauts who leave the Earth for Mars on 1 July 2037 could return to Earth?

b Suppose there are then unexpected technical problems in 2037 that take six months to sort out.
When could the first manned mission to Mars then depart?

c The Earth and Mars are relatively close to each other in July 2037. In July 2038, the distance between the two planets is greater, because the Earth takes 1 year to orbit the sun and Mars takes 1.88 years (about 22 months).
Make two sketches, one showing the positions of the sun, the Earth and Mars in July 2037 and one in July 2038.

d Why do you have to do a lot of sports during the journey to Mars?

3 Would you like to live on Mars? Write down why, or why not.

Course material overview

7.1 STARS, SUN AND MOON

REMEMBER

- As seen from the Earth, the stars move across the sky. They rise in the east, move up in a large arc to the south and then down again until they set in the west. This is because the Earth rotates around its own axis.
- The place where the sun rises shifts a little bit every day with respect to the stars. Over the course of the year, this means that the sun moves through all the constellations of the zodiac.
- The Earth's axis is at an angle to the plane of the ecliptic. This means that the northern hemisphere gets more sun for half the year: it is then summer and the days are longer. The other half of the year, it is the other way around (winter).
- The moon is lit by the sun. Depending on where the moon is with respect to the Earth, you will see more or less of its illuminated side. This is what causes the phases of the moon.

CONCEPTS

axial rotation
The Earth's movement around its own axis, which creates day and night.

constellation
Group of stars that create a recognizable pattern and that has been given its own name; well-known examples are Orion and Ursa Major (also known commonly in English as the Great Bear, the Plough and the Big Dipper).

Earth's axis
Imaginary line through the Earth's poles that the planet rotates around.

full moon
This is what the moon looks like when you are looking at the side that is lit by the sun: a large, round disc.

new moon
This is what the moon looks like when the dark side is facing the Earth; the moon is then invisible.

north celestial pole
Point in the sky that the northern end of the Earth's axis points towards; all the stars in the northern hemisphere appear to rotate around this point.

phase
Appearance of a planet or moon resulting from the fact that you can only see the part that is lit by the sun (and the unlit part remains invisible).

plane of the ecliptic
Plane of the Earth's orbit (which therefore also contains the sun).

zodiac
Strip of the sky containing twelve constellations that the sun moves through over the course of the year.

7.2 THE SOLAR SYSTEM

REMEMBER

- You can distinguish the planets because they move with respect to the background stars. If you look at them through a telescope, they each have their own distinctive appearance.
- Planets move around the sun in ellipses.
- In sequence of how far from the sun they are, the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.
- The terrestrial planets have hard, rocky surfaces. The gas giants are much larger than the terrestrial planets and they consist largely of gases.
- The astronomical unit (AU) is the average distance between the Earth and the sun. 1 AU = $150 \cdot 10^6$ km.

CONCEPTS

ellipse
Shape like a flattened circle.

gas giant
Planet that is much bigger than the Earth and consists largely of gases; these giant planets do not have a solid surface that you could land on.

planet
Spherical heavenly body that moves in an ellipse around the sun (or another star).

terrestrial planet
Planet that resembles the Earth in that it has a hard, rocky surface that planetary explorers could land on.

7.3 A PLANETARY ATMOSPHERE

REMEMBER

- Satellites can keep orbiting the Earth for years because there are no molecules that high to brake their motion.
- The atmospheres of the Earth, Venus and Mars consist of different mixtures of gases. The Earth's atmosphere is mostly nitrogen, with oxygen next most abundant. The atmospheres of Venus and Mars consist mostly of carbon dioxide.
- Oxygen is indispensable for the people (and animals) living on the Earth because we can't breathe without it. Plants need carbon dioxide to grow.
- Air pressure is caused by the weight of the air above you.
- Generally the air pressure inside you is the same as on the outside and so you don't notice anything.
- Air pressure is measure with a barometer. Meteorologists use the hectopascal (hPa) as the unit or air pressure.
- Air pressure decreases with height. This is because the amount of air still above you becomes less and less.

CONCEPTS

air pressure
Pressure of the atmosphere on Earth.

atmosphere
Name for the mixture of gases that forms the outermost layer of a planet.

atmospheric pressure
Pressure created by the weight of all the gases in the atmosphere above your head.

barometer
Instrument used for measuring atmospheric pressure.

counter-pressure
Pressure of the gases inside a hollow object, working against atmospheric pressure.

standard pressure
Average air pressure on Earth at sea level, 1013 hPa.

vacuum
Area where there are no molecules at all – literally 'empty space'.

7.4 THE STRUCTURE OF THE UNIVERSE

REMEMBER

- A star chart lets you find out where the stars, planets and constellations will be in the sky at a given time.
- A star is an enormous ball of glowing, hot gases. The sun is the star that is nearest to us.
- Triangulation involves looking at a star twice, once in the summer and once in the winter. You then measure the angle you can see the star at each time. Using those two angles and the baseline (the diameter of the Earth's orbit), you can determine the distance to the star.
- A lightyear (ly) is the distance that light travels through space in one year.
- 1 ly = $9.46 \cdot 10^{12}$ km and 1 ly = $63 \cdot 10^{3}$ AU.
- A good telescope will let you discover lots of galaxies in the sky. In our own galaxy, you can see the individual stars that are near to the sun and the Milky Way itself as a band of light.
- Billions of galaxies are visible in the universe. The galaxies that are furthest away are at distances of billions of lightyears from the Earth.

CONCEPTS

baseline
Line of known length that you use for triangulation: the angles are measured from the ends of the baseline.

galaxy
Collection of hundreds of billions of stars grouped together, often with striking, spiral-shaped arms.

Milky Way
The galaxy that the sun and the Earth belong to. Also a band of light that can be seen across the night sky.

star chart
Map of the stars in the sky as it can be seen on a cloudless night.

triangulation
Way of using two angles measured from the ends of a known baseline to determine the distance to an object.

Go to the *Flash cards* and the *Diagnostic test*.

8 Sound

SOUND AROUND YOU

A world without sounds is difficult to imagine. What would the world be like without music, a nice chat, or the sound of the wind and the sea? And also without the racket of cars racing past, planes taking off and antisocial neighbours?

1 Making and hearing sounds

LEARNING OBJECTIVES

8.1.1 You can give a number of examples of sound sources.
8.1.2 You can explain how the sound from a sound source spreads until it reaches your ears.
8.1.3 You can describe what a medium is.
8.1.4 You can say what the speed of sound is in air at 20 °C.
8.1.5 You can do calculations using the speed of sound in various media.
EXTRA 8.1.6 You can explain how your vocal cords work when you talk.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	8.1.1	8.1.2	8.1.3	8.1.4	8.1.5	8.1.6
Remembering	1abc	2abcd				
Understanding		5abc	3ab, 6, 11c	7a		12abcd
Using			4ab		3c, 7b, 8ab, 9, 11b	13ab
Analysing					10, 11a	

Sound is everywhere in nature. Think of thunder rumbling, the crashing of waves on the seashore and all the animal noises. People make and create sounds as well. They talk, sing, shout, make music, drive cars and so forth.

SOUND SOURCES

EXP 1 An object that makes a noise is referred to as a **sound source.** Many sound sources are made by humans, such as musical instruments, firecrackers, motorbikes and loudspeakers. Other sounds come from natural sound sources, such as the sound of your voice, birdsong or thunder.

Sound is produced by vibrations in or of a sound source:

- In the case of your voice, the vibrations are in your vocal cords.
- In a loudspeaker, the part that vibrates is the cone (figure 1).
- In a guitar, the strings vibrate (making the sound box vibrate).

You hear that vibration as a sound because the vibration moves from the sound source to your ears. You can compare that movement to the ripples in water when you throw in a stone. The splash can be compared to the sound source. The ripples in the water are the sound moving.

figure 1 When a loudspeaker is producing a sound, you can feel the cone vibrating.

FROM THE SOUND SOURCE TO YOUR EARS

EXP 1

The cone of a loudspeaker is a thin sheet of paper or plastic. When the loudspeaker is producing a sound, the cone vibrates. This creates pressure differences in the air. When the cone moves outwards, the molecules next to it are forced closer together (which increases the air pressure). When the cone moves inwards, conversely, the molecules get more space (so the air pressure drops). The drawing in figure 2 shows how the sound from a loudspeaker spreads.

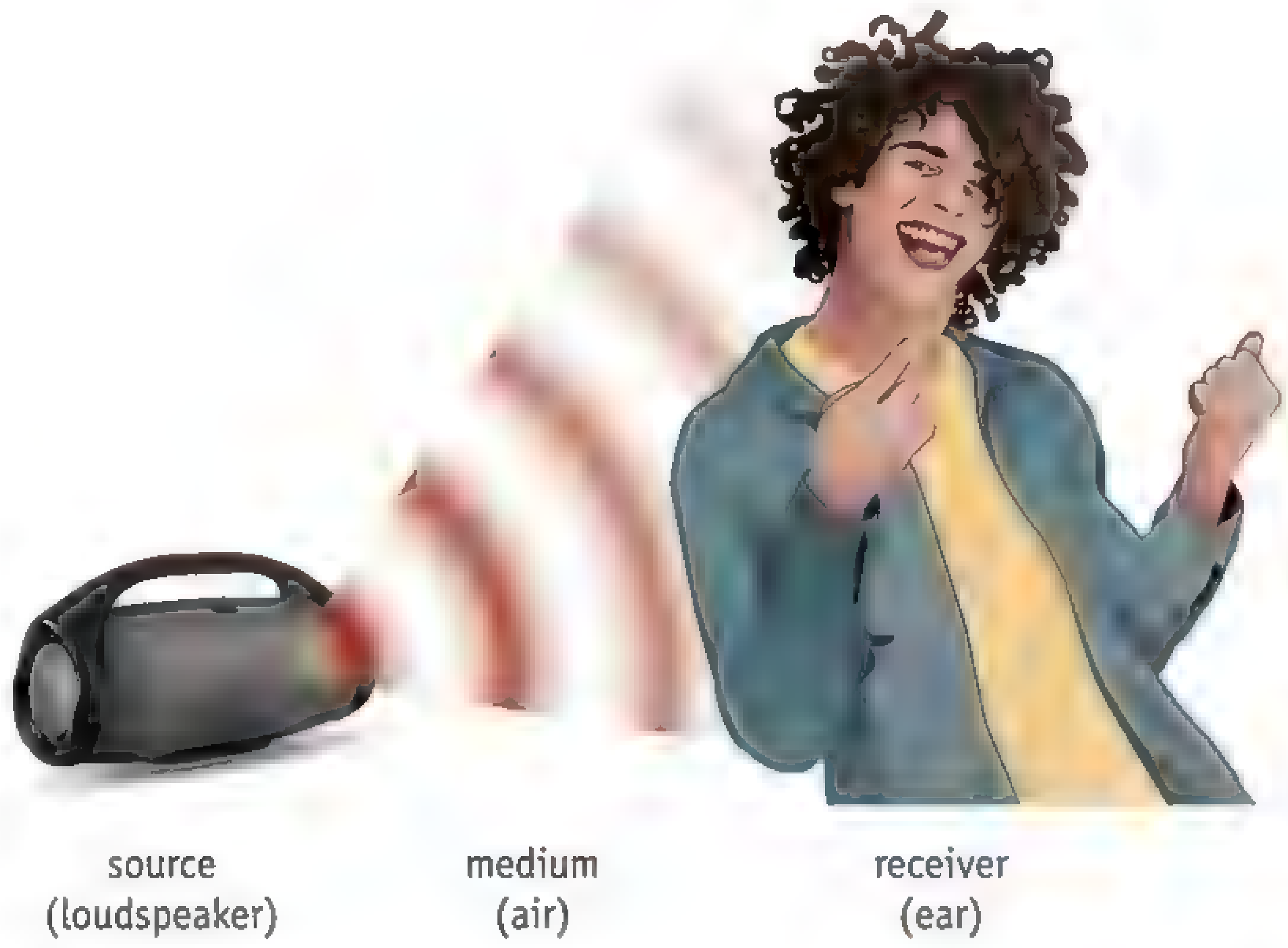


figure 2 Air pressure changes at a loudspeaker.

Because the molecules are continually colliding with one another, their movements get passed from one to the next. The movements of the molecules close to the cone are passed on to the molecules that are further away from the cone. The net result is that the pressure changes move away from the loudspeaker in all directions. And when those pressure changes reach your ears, you hear the sound. So the pressure changes are what move, not the molecules.

You can only hear sound when there is a **medium** to carry it: a substance that the vibrations can pass through from the sound source to a receptor (your ears). Most sounds reach your ears through the air. But sound can also travel through liquids and solids (such as metal). You hear the sound of your voice, for example, not only from the outside (through the air) but also from the inside (through your skull).

THE SPEED OF SOUND

Sound takes time to propagate through a medium. The speed at which sound travels varies from one material to another. The speed of sound in air at 20 °C is 343 m/s. That's more than 1200 km/h! Table 1 shows you what the **speed of sound** is in various materials.

table 1 The speed of sound in various solids, liquids and gases at 20 °C.

substance	speed of sound (m/s)
solids	
concrete	4300
glass	4000-4500
cork	500
rubber	50
steel	5100
liquids	
alcohol	1170
water	1480
seawater	1510
gases	
helium	965
carbon dioxide (CO_2)	259
air	343

You can use sound to calculate the distance between the sound source and the receiver. To do that, you have to know the speed of sound and know (or measure) how long sound took to travel from the source to the receiver (figure 3). Then you use the formula:

distance = speed of sound × time

or in symbols:

$$s = v \cdot t$$

where:
- s is the distance in metres (m);
- v is the speed of sound in metres per second (m/s);
- t is the time in seconds (s).

figure 3 The sound of thunder has a speed of about 343 m/s.

EXAMPLE EXERCISE 1

Isabelle is out for a walk at the end of a hot day. She sees lightning strike in the distance (figure 3). She counts three seconds before she hears the thunder.
How far away from Isabelle did the lightning strike?

given $v = 343$ m/s
$t = 3$ s

required $s = ?$

working $s = v \cdot t$
$= 343 \times 3 = 1029$ m

So the distance was roughly 1 km.

As you can see, there is no need to make any allowance for the time that light needs to get to your eyes. This is because the speed of light is so fast: about 300,000 km/s!

HEARING SOUNDS

Figure 4 is a drawing of the inside of an ear. When the pressure differences reach the ear, the eardrum vibrates along with them.

- The eardrum moves inwards when the air pressure at A increases.
- The eardrum moves outwards when the air pressure at A decreases.

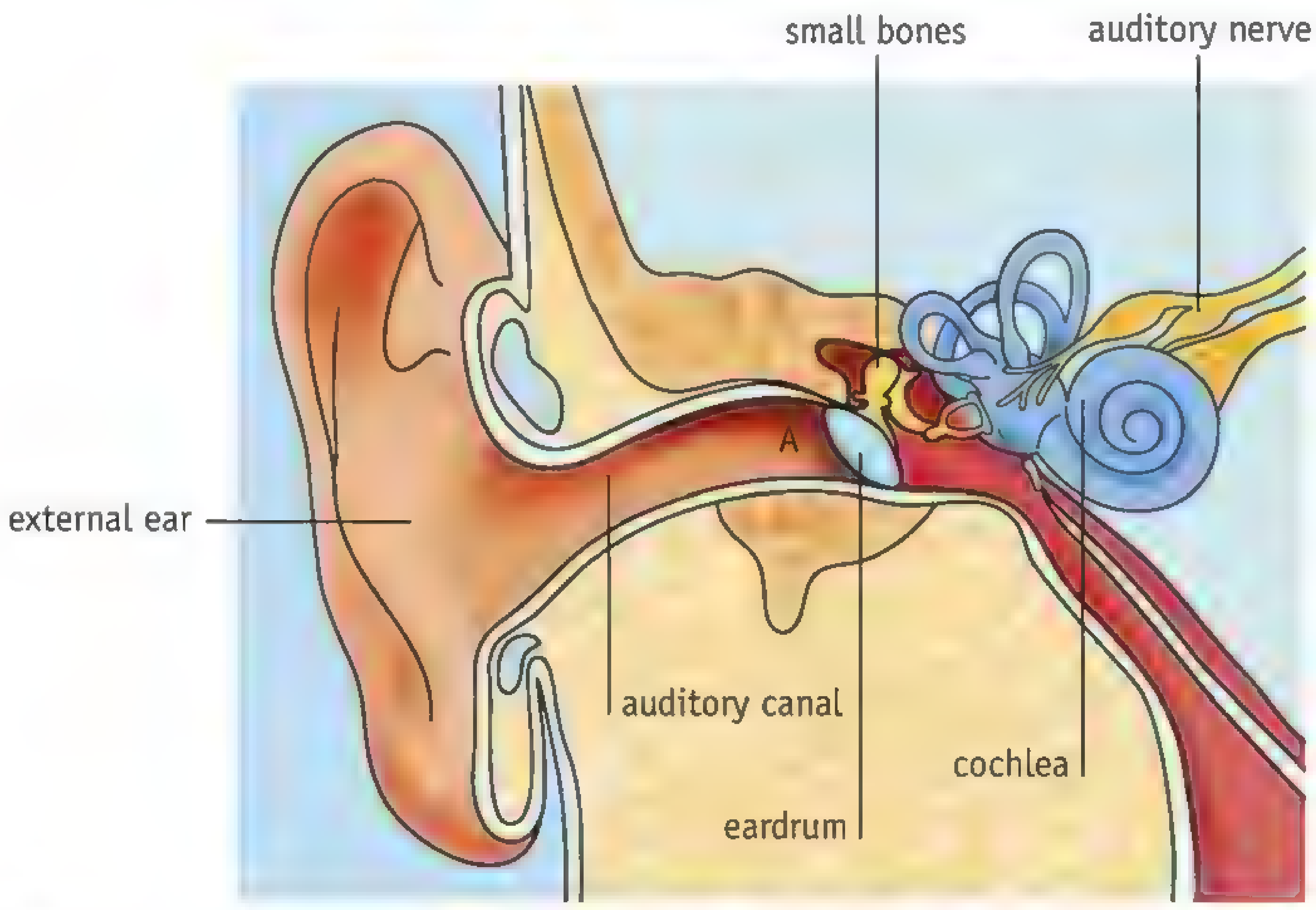


figure 4 The inside of your ear.

The eardrum therefore vibrates along with the changes in the air pressure. The small bones in the ear transmit the vibrating movement of the eardrum to the liquid in the cochlea. This also amplifies the sound.

Auditory cells in the cochlea translate the vibrations into electrical signals. These signals are transmitted along the auditory nerve to the brain. You only become aware of the sound when your brain receives these signals: you hear the sound.

Practice the concepts using the *Flash cards*.

EXTRA THE HUMAN VOICE

The 'speech organ' comprises the vocal cords, the cavities in the mouth, throat and nose, and the tongue and the lips (figure 5). When you speak, your vocal cords close up. Your lungs then force air through the glottis, the small gap between the vocal cords (figure 6). Your vocal cords then begin to vibrate, as you will be able to feel if you touch your throat with your fingertip.

figure 5 Your speech organ.

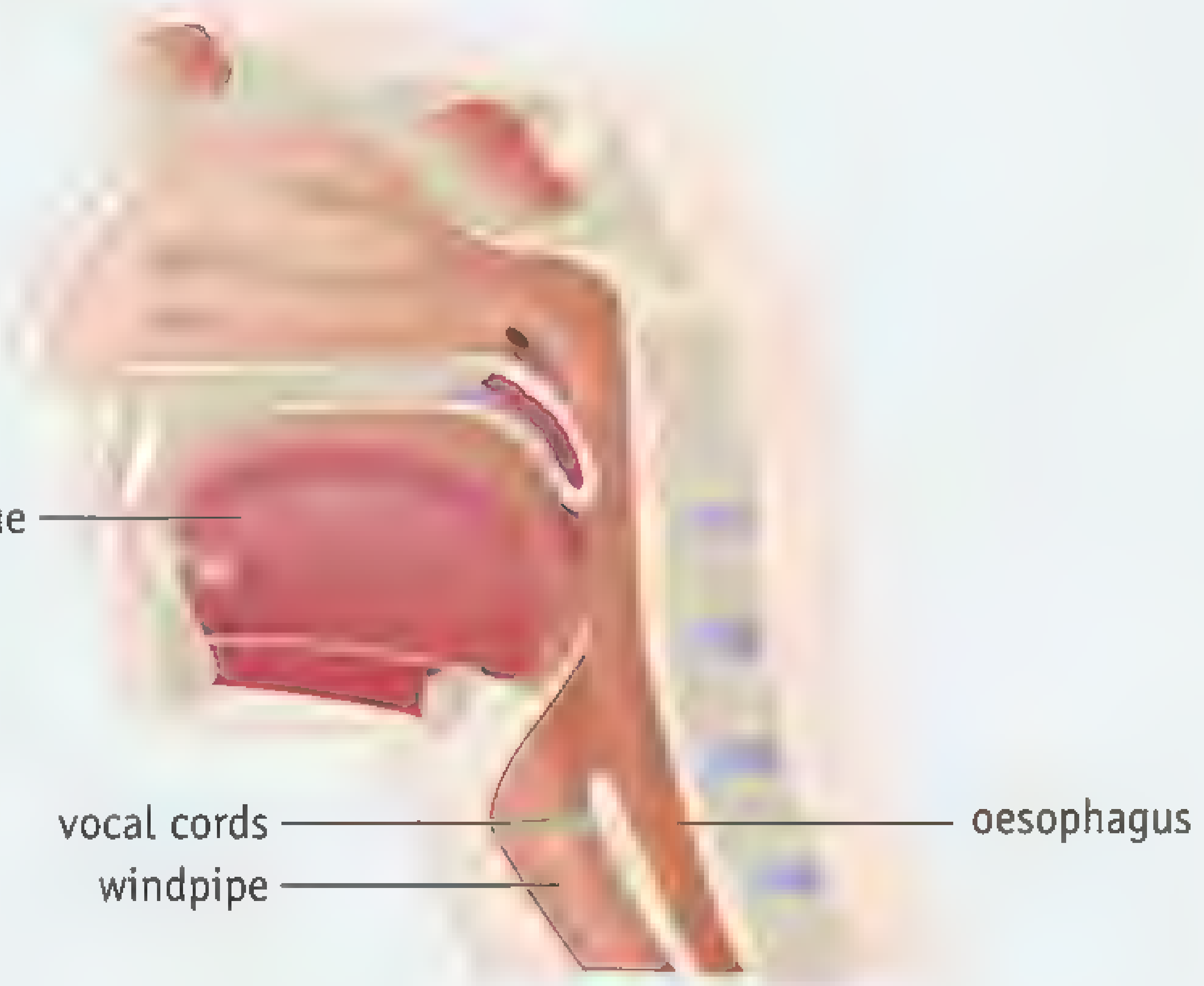
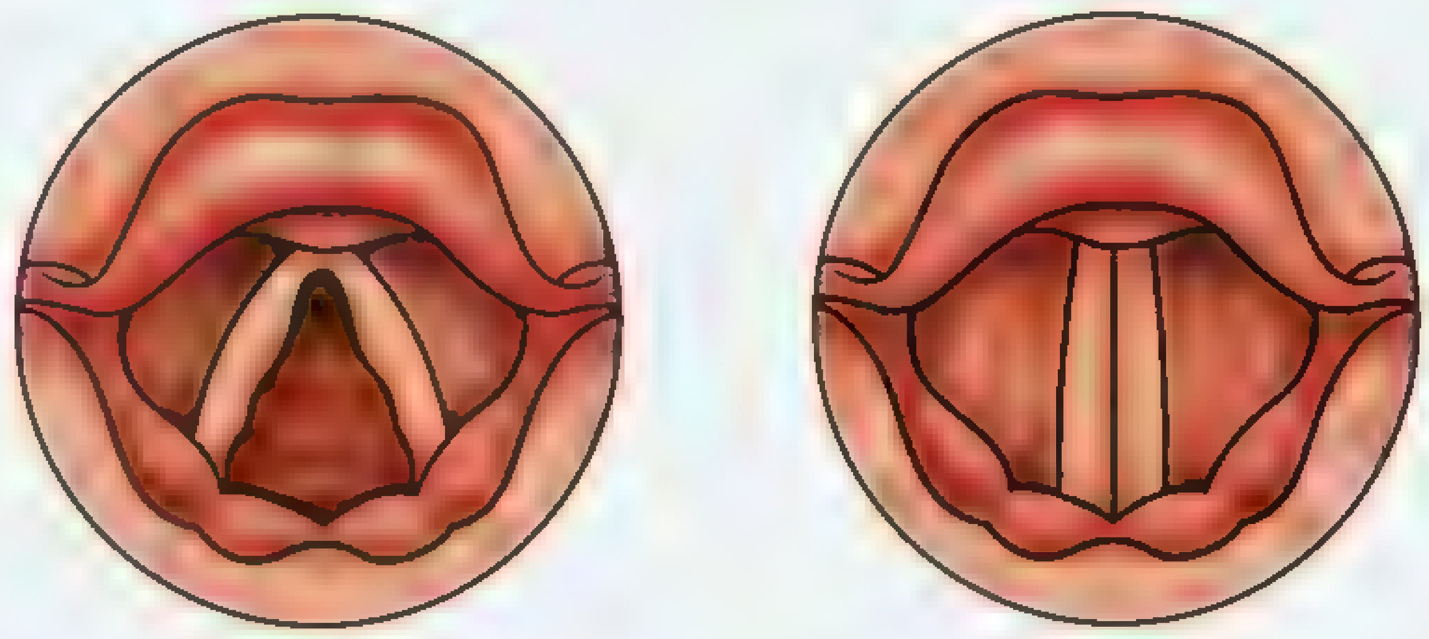


figure 6 How your vocal cords work.



If you are only breathing, the vocal cords are open.

If you are talking or singing, the vocal cords are closed.

There are muscles that let you alter the tension of the vocal cords, which lets you control the pitch of your voice. Changing the shape of the cavity in your mouth lets you distort the sound of the vocal cords. Try making a long vowel "ah" and then a long vowel "oh". You will be able to feel the shape of your mouth cavity changing.

You can also make sounds without using your vocal cords, for example when you say an S or a P. For a P, you close the airflow off with your lips, so that a bit of pressure accumulates behind them. That pressure is released when you relax your lips. The result is an 'explosion' of air flowing outwards.

COURSE MATERIAL

1 Sound is caused by vibrations. What is vibrating in:

a an acoustic guitar that is being played?
b a loudspeaker that music is being played through?
c your throat when you are talking or singing?

2 A loudspeaker is an example of a sound source.

a What are created in the air when the cone starts vibrating?
b How does sound travel from the loudspeaker to your ears?
c Which part of your ear vibrates when the sound arrives there?
d Where in your ear are the vibrations turned into electrical signals?

IN PRACTICE

3 In westerns you sometimes see someone putting an ear down to the rail tracks so that they can hear a train coming from a long way away.

- **a** What medium is the sound being propagated through in this case?
- **b** How fast does sound travel through that material?
- **c** A train is 3.0 km away from the person who has put their ear to the track. Calculate how long the sound of the train takes to reach that person.

4 Matt sets up the experiment shown in figure 7. He sets the bell ringing and pumps the air out from inside the bell jar.

- **a** What change will there be in the sound that Matt can hear?
- **b** Why?

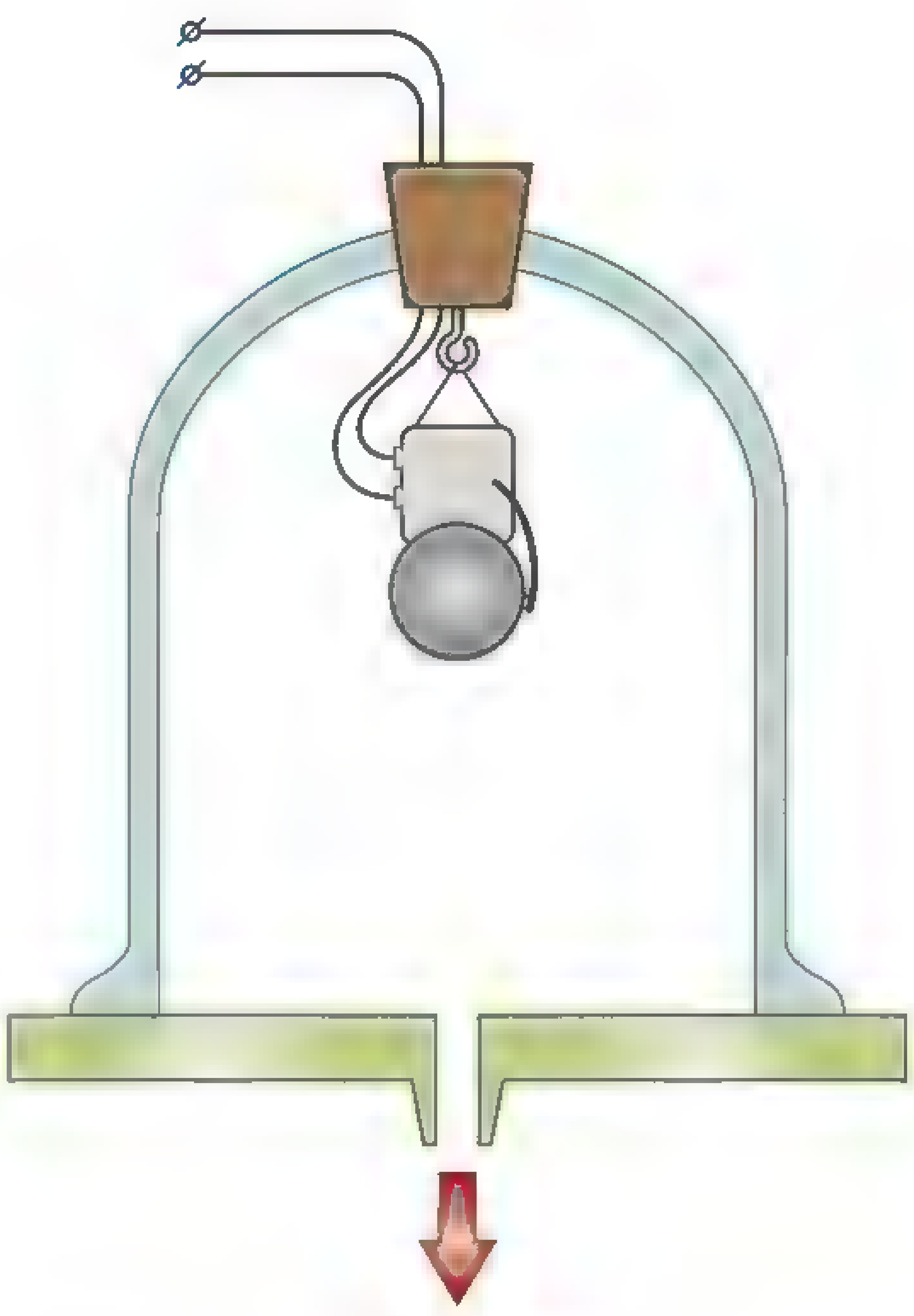


figure 7 A bell under a bell jar.

5 When you are listening to a podcast, you hear the presenter's voice. Various sound sources, mediums and receptors of sound are involved.
Select the correct term each time.

- **a** The presenter's voice is transmitted to the microphone through the air.
  - presenter: *sound source / receptor / medium*
  - air: *sound source / receptor / medium*
  - microphone: *sound source / receptor / medium*
- **b** In the microphone, the sound is converted into small electric currents that go to the computer through the cables.
  - microphone: *sound source / receptor / medium*
  - cables: *sound source / receptor / medium*
  - computer: *sound source / receptor / medium*
- **c** When you are listening to a podcast, the headphones are the *sound source / receptor / medium* and the air is the *sound source / receptor / medium* that carries the sound to you. Your ears are the *sound source / receptor / medium*.

6 Lisa's class presentation was recorded. When the clip is played back, she does not like what she hears at all. "My voice sounds completely different to what I normally hear when I'm talking," she grumbles.
Why does your voice sound so different when you hear a recording of it? Tip: think of the media that are involved in transmitting it.

7 There is thunder in the distance. Fatima sees a flash of lightning. She hears the thunderclap eight seconds later.

a What speed does the sound come towards Fatima at?
b Work out how far away Fatima is from the thunderstorm. Give your answer in kilometres.

8 Tim says, "It's easy to work out how far away you are from a thunderstorm. Count the seconds between the lightning flash and the thunder, and then divide that by three. That gives you the distance in kilometres."

a Work out how long it takes sound to travel 1 km according to Tim.
b Is that consistent with the speed of sound stated in table 1? Do a sum to show this.

★ 9 A building has concrete walls that are 50 cm thick. Mana is sitting 3.0 m from the wall. Somebody then knocks on the outside of the wall.
Work out how long it takes before Mana hears the knocking. Round the answer off to three decimal places.

★ 10 A ship is using sound to measure the depth of the ocean. The sonar system sends out a short pulse of sound and then picks up the reflected signal (the echo) a little later. Have a look at figure 8. The time between emitting the sound and receiving the echo is 0.42 s. Calculate how deep the ocean is, in metres.

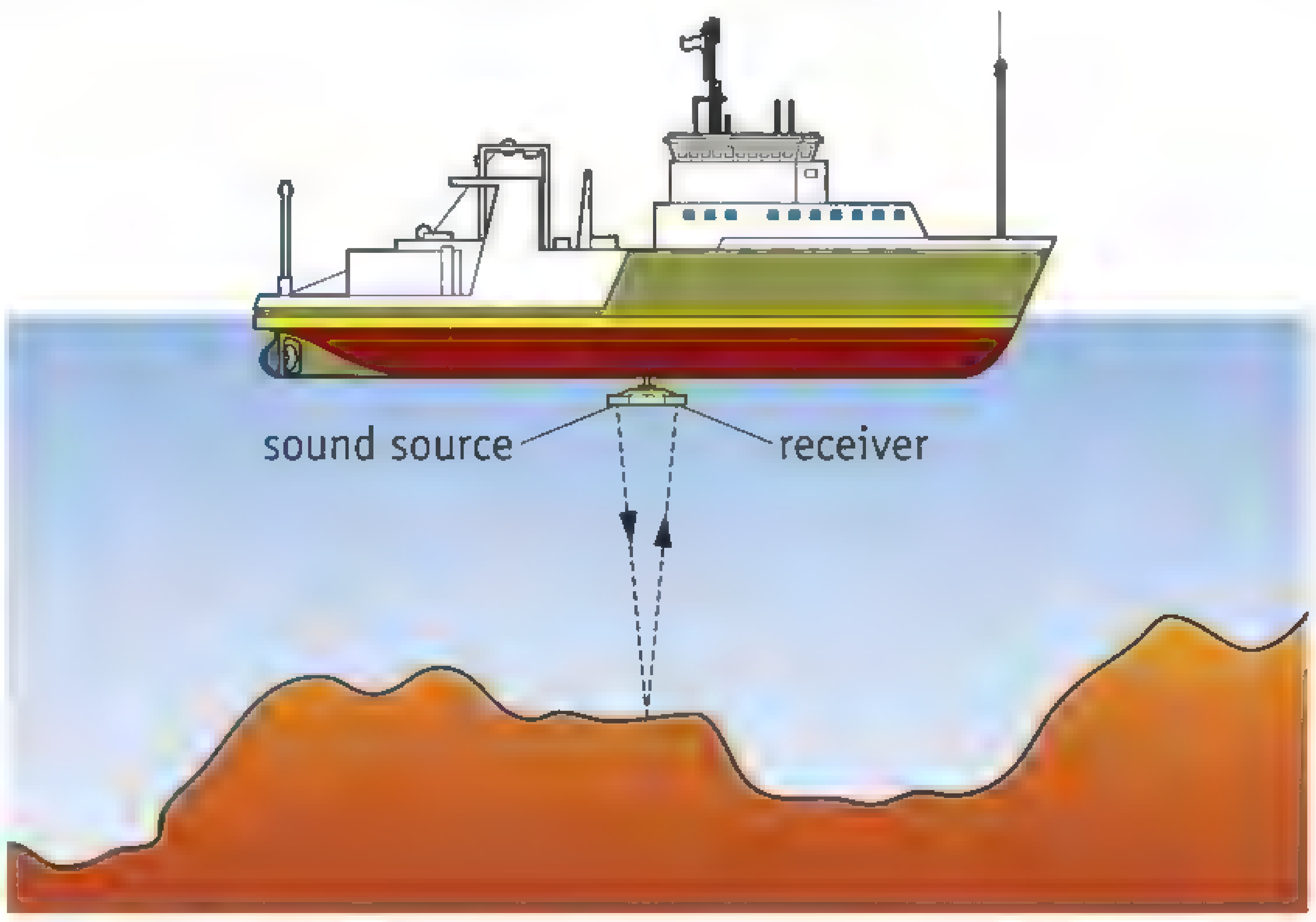


figure 8 How deep is the ocean?

★ 11 The scientists Colladon and Sturm measured the speed of sound in water in 1827 on Lake Geneva. They used a bell and a tube. The bell let them make a noise under the water and the tube let them hear it under the water. A visual signal was given at the same time as the bell was rung (figure 9). Their measurements said the sound of the bell took 9.3 s to travel a distance of 13.4 km underwater.

a Why did they not have to make any allowance for the time that the light from the signal took to reach them?
b What value did they determine for the speed of sound in water?
c The speed of sound depends on the temperature of the water. What was the temperature of the water, roughly? Use table 2.

table 2 The speed of sound in water at various temperatures.

water temperature (°C)	speed of sound (m/s)
0	1403
20	1484
40	1529
60	1540
80	1555

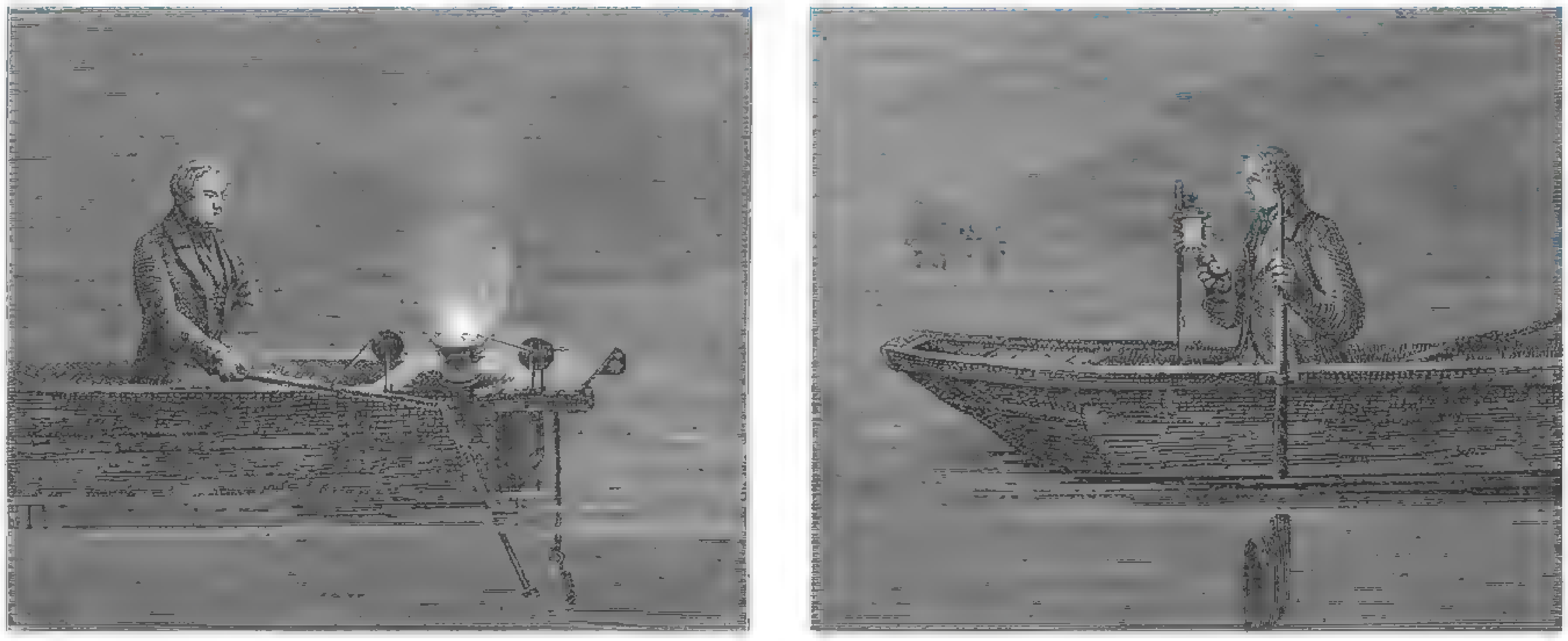


figure 9 Colladon and Sturm at work.

Test what you know with *Test yourself*.

EXTRA THE HUMAN VOICE

12 People can use their organs of speech to produce all sorts of sounds.
Indicate for each sound where it originates. Choose between: *at the back of your throat – in your oral cavity – between your lips – between your tongue, the hard palate and the front teeth.*

a The sound when you whistle.

....

b The sound when you cough.

....

c The sound when you make a hissing sound (letter 's').

....

d The sound when you say the letter 'A'.

....

13 The letter P is called a plosive because the pressure builds up in your mouth and the sound is produced when it 'explodes'.

a Think of another example of a plosive.

b For which letters is there no build-up of pressure in the mouth?

2 Pitch and frequency

LEARNING OBJECTIVES

8.21. You can write down three factors that affect how high the tone is that a string produces.
8.2.2 You can explain what the frequency of a vibration is.
8.2.3 You can determine the vibration period of a tone in an oscilloscope trace.
8.2.4 You can do calculations using the vibration period and frequency.
8.2.5 You can give the frequency range of human hearing.
EXTRA 8.2.6 You can explain the difference between ultrasound and infrasound.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES						
	8.2.1	8.2.2	8.2.3	8.2.4	8.2.5	8.2.6	5.2.1*
Remembering	2ab, 3	1ab			1cd		
Understanding	4	6de, 10bc	6ab, 8b, 11a		10a	12abd, 13a	
Using		5	8a	9abcd, 6c		12c	
Analysing		10d	7	9d, 11b		13bc	11c

* You can find this learning objective in an earlier section.

If you want to describe a sound, there are various words you can use. Those words often have something to do with the pitch. You might for example say that a broken loudspeaker squeals (makes a high note), rumbles (makes a low note) or buzzes (somewhere in between). The pitch would seem to be an important property of the sound.

STRINGED INSTRUMENTS

EXP 4

All sorts of musical instruments use strings. A violin has four strings, for example. A guitar usually has six and a piano has more than two hundred. If you make a string vibrate, it produces a tone: a sound with a definite pitch. Most people can then sing the same note without much difficulty.

How high a tone a string produces depends on three factors:
1 the thickness of the string: the thicker the string, the lower the tone;
2 the length of the string: the longer the string, the lower the tone;
3 the tension in the string: the lower the tension, the lower the tone.

A stringed instrument can be **tuned** by adjusting the string tensions correctly (figure 1). You can use a tuning fork or an electronic tuner to determine the correct pitch.

figure 1 A guitarist changes the pitch by altering the tension in the string.

FREQUENCY

When you strike a tuning fork, the arms of the tuning fork start to vibrate. They always move back and forth the same number of times in one second. You can investigate this motion using a tuning fork with a wire hook attached to one of the prongs. You can then strike the tuning fork and drag the wire hook along a glass slide covered with lampblack (soot) on one side. You will see that it leaves a wavy trail.

Figure 2 shows you part of a wavy track made this way. The hook has made one complete vibration between A and B. If you draw the tuning fork plus wire hook along the glass slide for exactly one second, you will record a large number of vibrations. If you count them, it will tell you exactly how many vibrations there are per second. This is called the **frequency** (*f*) of the vibration.

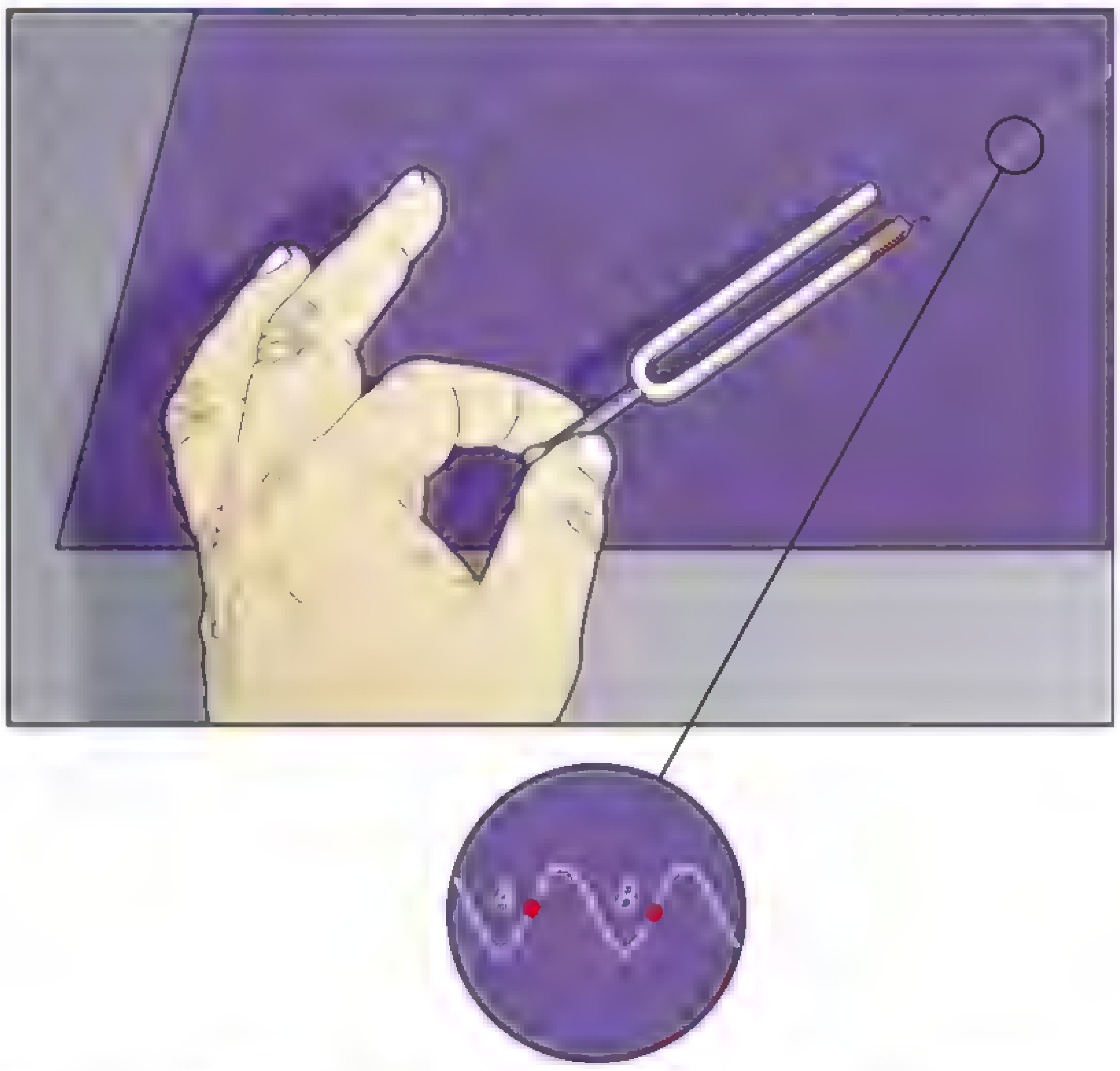


figure 2 This lets you visualize the vibrations of a tuning fork.

Frequencies are measured in hertz (Hz). If the frequency is 128 Hz, this means that the prongs of the tuning fork move back and forth 128 times every second. The higher the frequency, the higher the pitch of the tone you hear. A 440 Hz tuning fork, for example, gives a higher note than a 128 Hz tuning fork. A tone generator lets you set the frequency of a tone.

Whether a tone sounds high or low to you is subjective. You may think it is high, for instance, while others don't – but there is a relationship: when the frequency increases, a sound is more high-pitched. A high-pitched piccolo (a small flute), for example, emits very high frequencies with thousands of vibrations per second. On the other hand, the sound of a tuba is very low-pitched and has a low frequency. Figure 3 shows you the vibration of two tones, where one tone is higher than the other.

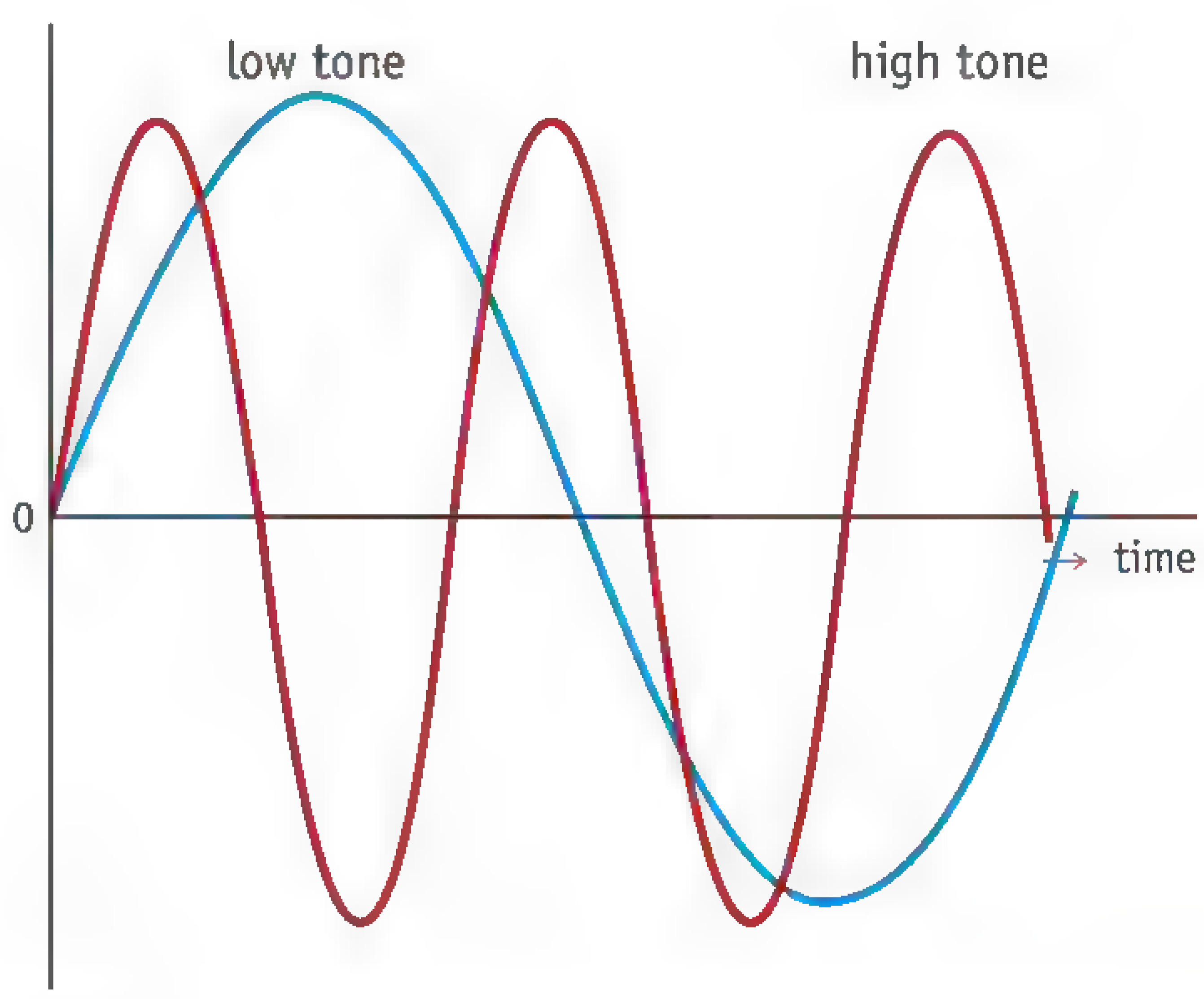


figure 3 A higher tone has more waves per second than a lower tone.

VIBRATION PERIOD

EXP. 6

The experimental setup in figure 4 lets you investigate sound vibrations. The **microphone** converts the pressure differences of the sound into an electrical signal. The **oscilloscope** then shows that signal on the screen. This lets you investigate how rapidly the air pressure is changing. There are also programs that let you turn your computer, tablet or smartphone into an oscilloscope.

A set of axes is shown on the oscilloscope screen. Time is presented along the horizontal axis. You can use the knobs on the oscilloscope to set the time scale. This is referred to as selecting the **time base.** In figure 4, the time base is set to 1 ms per division. That means that every square is one millisecond 'wide'.

The four vibrations on the oscilloscope screen take up nine squares altogether. That means that the four vibrations take a total of 9 × 1 = 9 ms. So a single vibration needs $\frac{9}{4}$ = 2.25 ms. The time required for a single complete vibration is called the **vibration period** (T). You say that the period of the vibration of the tuning fork in figure 4 is 2.25 ms. In figure 5, the vibration period is shown in a graph.

figure 4 This is how you can determine the vibration period of a tuning fork.

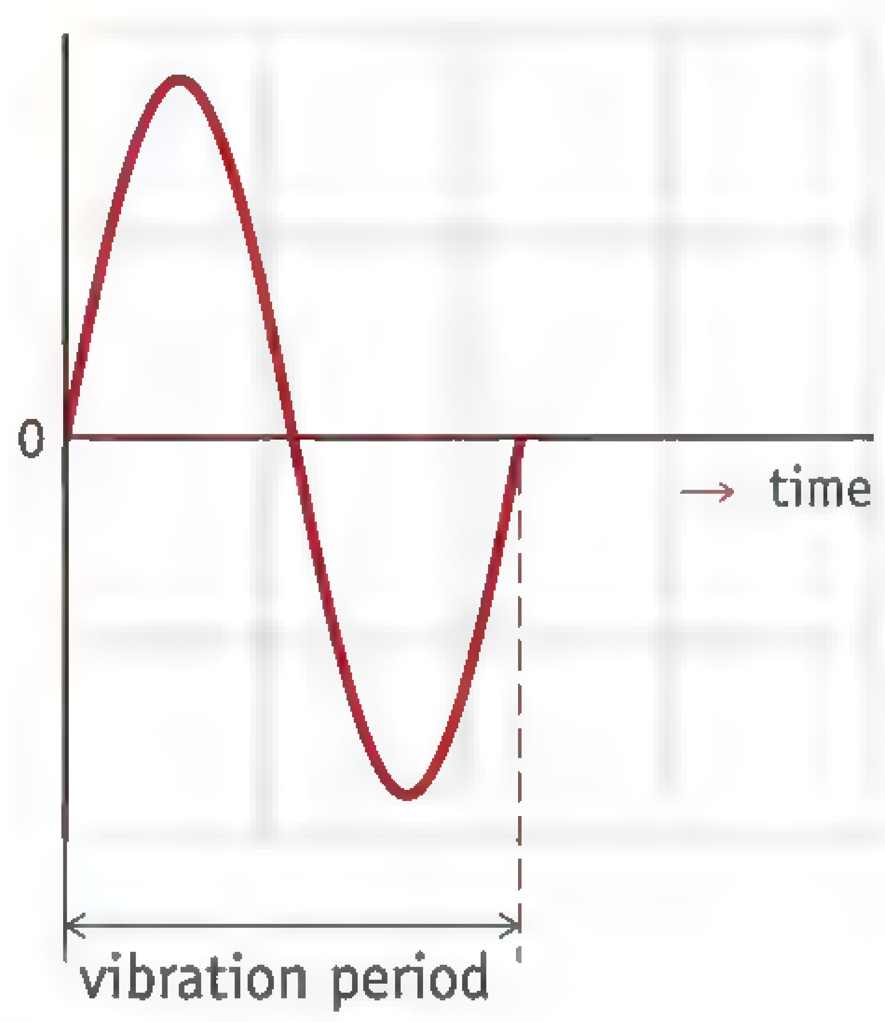


figure 5 The vibration period.

THE PERIOD AND FREQUENCY OF A VIBRATION

If you know the period of a vibration, you can calculate its frequency. If the vibration period is 0.1 s, there will be 10 vibrations in 1 s. And so the frequency is 10 Hz. If the vibration period is 0.01 s, there will be 100 vibrations in 1 s. And so the frequency is 100 Hz. And so forth.

You can calculate the frequency using this formula:

$$\text{frequency} = \frac{1}{\text{vibration period}}$$

Or in symbols:

$$f = \frac{1}{T}$$

where:

- f is the frequency in hertz (Hz);
- T is the vibration period in seconds (s).

EXAMPLE EXERCISE 1

Calculate the frequency of the tuning fork in figure 5.

given $T = 2.25 \text{ ms} = 0.00225 \text{ s}$

required $f = ?$

working $f = \frac{1}{T} = \frac{1}{0.00225} = 444 \text{ Hz}$

THE FREQUENCY RANGE OF YOUR HEARING

You are not able to hear sounds with very low or very high frequencies. Most people of your age can hear tones between 20 Hz and 20,000 Hz. You say that the tones are within the **frequency range** of your hearing. As you get older, the frequency range of your hearing changes. In particular, you are less able to hear high-pitched tones.

Practice the concepts using the *Flash cards*.

EXTRA ULTRASOUND AND INFRASOUND

Sound at frequencies above 20,000 Hz is called ultrasound. Humans cannot hear these sounds, but some other animals can. Dogs for example have no difficulty hearing an ultrasonic whistle at 35,000 Hz.

Bats and dolphins regularly produce ultrasound noises. Listening to the echoes of these sounds lets them perceive their surroundings. Bats use this method to detect insects (figure 6). Ultrasound is used in hospitals for making scans – sonograms – that can for example let you see the baby in the womb of a pregnant woman.

figure 6 A bat uses sound for hunting.

Sounds with frequencies lower than 20 Hz are known as infrasound. People cannot hear those sounds either, although you can feel them if they are loud enough. Elephants can use infrasound to communicate with one another over vast distances.

COURSE MATERIAL

1 Answer the following questions.

a What is meant by 'the frequency of a vibration'?
b What units are used for measuring frequency?
c What does 'the frequency range of your hearing' mean?
d What is the frequency range of hearing for young people with normal hearing?

2 How does the pitch of a guitar string change if the guitarist:

a increases the tension in the string?
b puts his finger on the string so that the vibrating part becomes shorter?

3 Two strings are equally long. One string nevertheless sounds lower than the other. Write down two possible causes.

IN PRACTICE

4 A piano tuner uses a tuning key to tighten or loosen the piano strings (figure 7). First of all, they tune a string that is intended to give a tone of 440 Hz.
Explain what the piano tuner must do if that string gives a tone of 445 Hz.

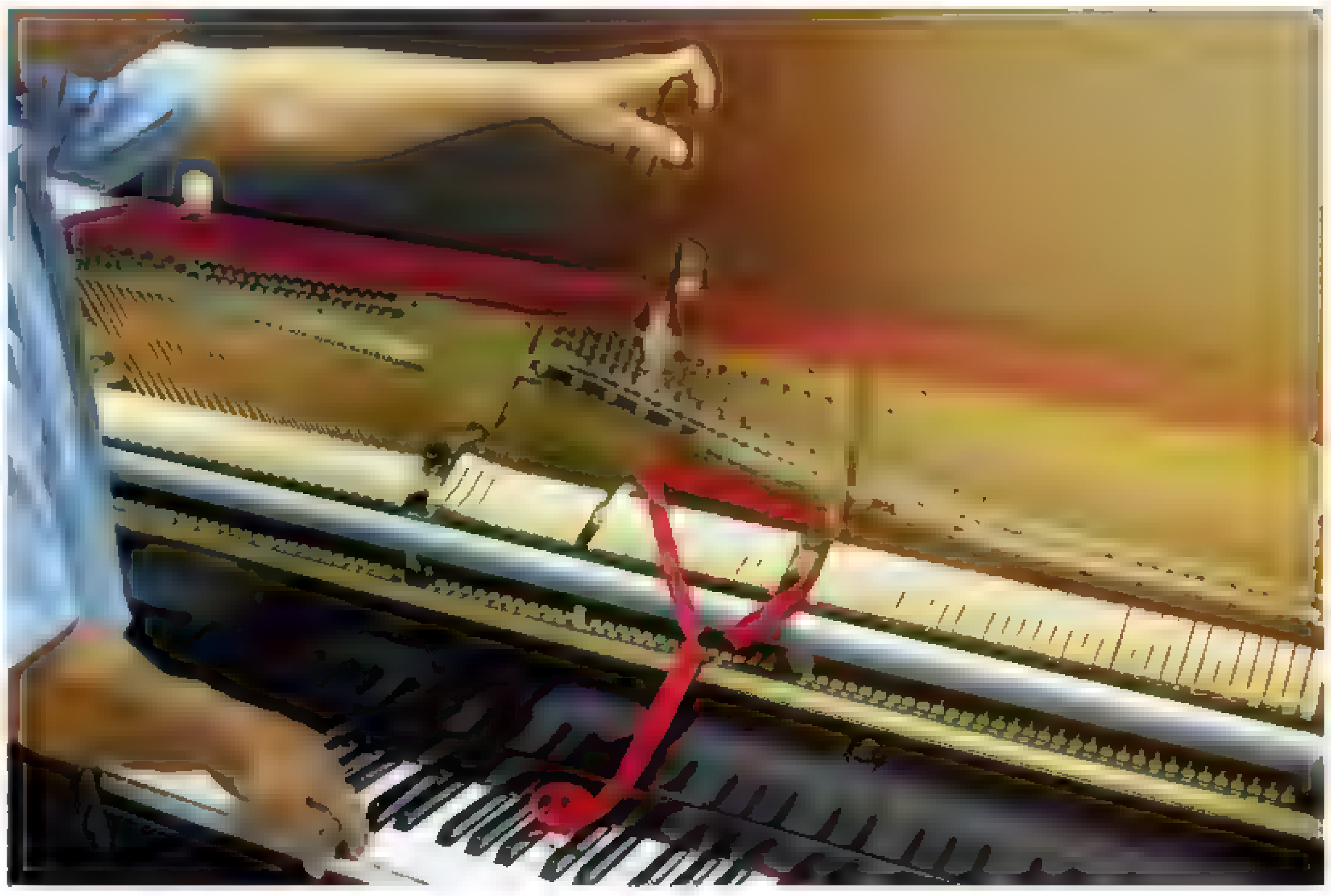


figure 7 Tuning a piano using a tuning key.

5 The buzzing of a gnat sounds much higher than the buzzing of a bee.
Which insect is moving its wings up and down more times per second? Explain your answer.

6 Three tones (a, b and c) are shown successively on an oscilloscope (figure 8). The time base is stated for each of the screens.

See the Skills section on *Working with an oscilloscope*.

a See figure 8a. Complete:

Each square on the screen represents .... ms.

One complete vibration is .... squares wide.

The vibration period is therefore .... × .... ms = ... ms.

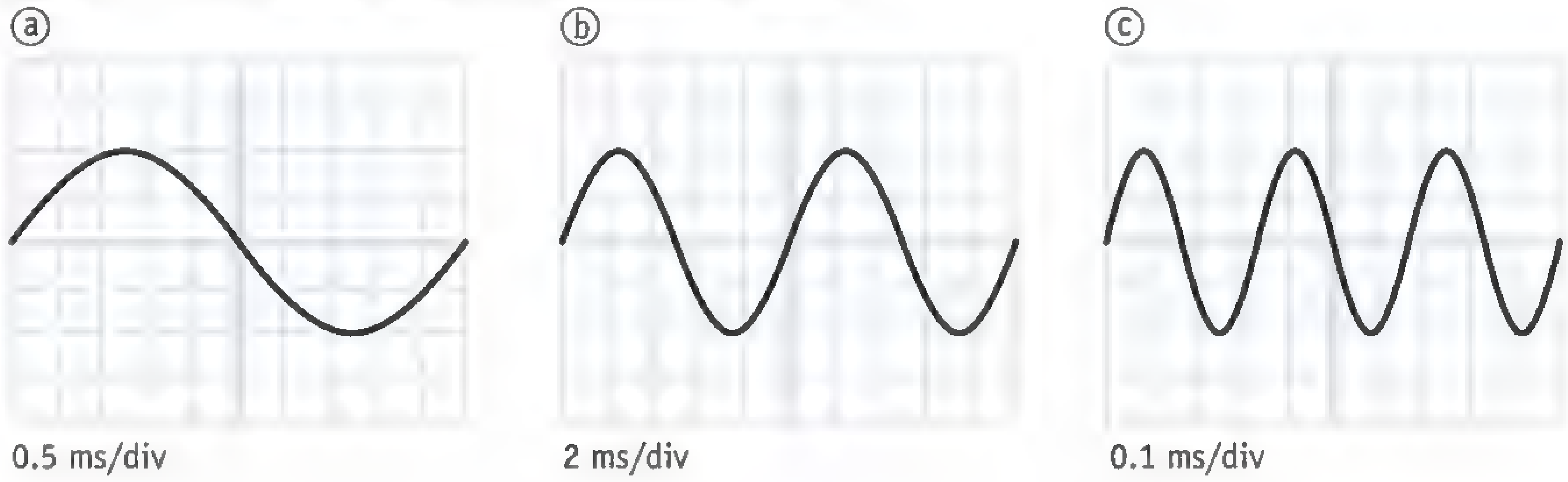
b Determine the vibration periods for tones (b) and (c) in the same way.

c Calculate the frequencies of tones a, b and c.

d Which oscilloscope picture is showing a high-pitched beep?

e Which oscilloscope trace is showing a low-pitched hum?

figure 8 Three different tones on an oscilloscope screen.



7 Max is looking at two tones on an oscilloscope, using the same time base. Figure 9 shows you the oscilloscope trace representing the first tone.
The frequency of the second tone is twice as high as the first one. Sketch the oscilloscope trace for the second tone in the figure.

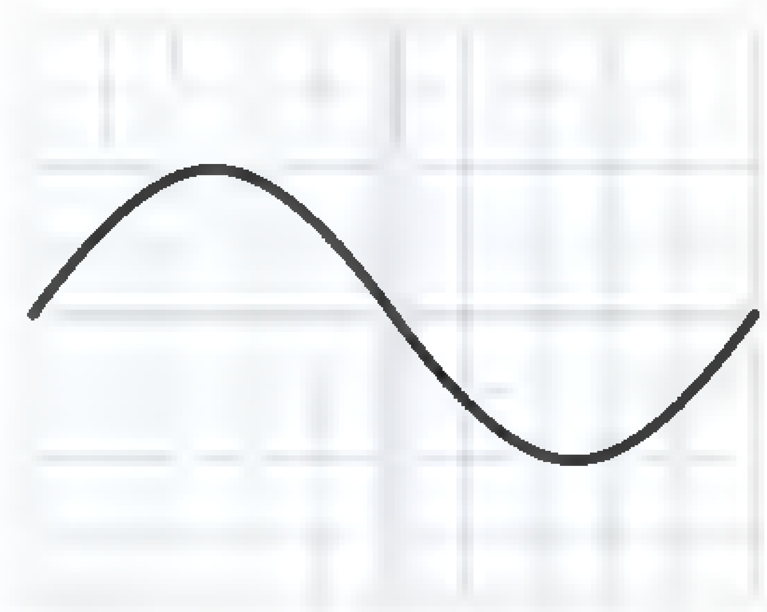


figure 9 What does a tone with twice the frequency look like?

8 Julia is testing a sound system with an oscilloscope app that can produce various test tones. Figure 10 shows how the oscilloscope represents one of the test tones. The time base has been set to 0.2 ms/div.

a Determine the frequency of this test tone.

b How many vibrations will Julia see on the screen if she changes the time base to 1 ms/div?

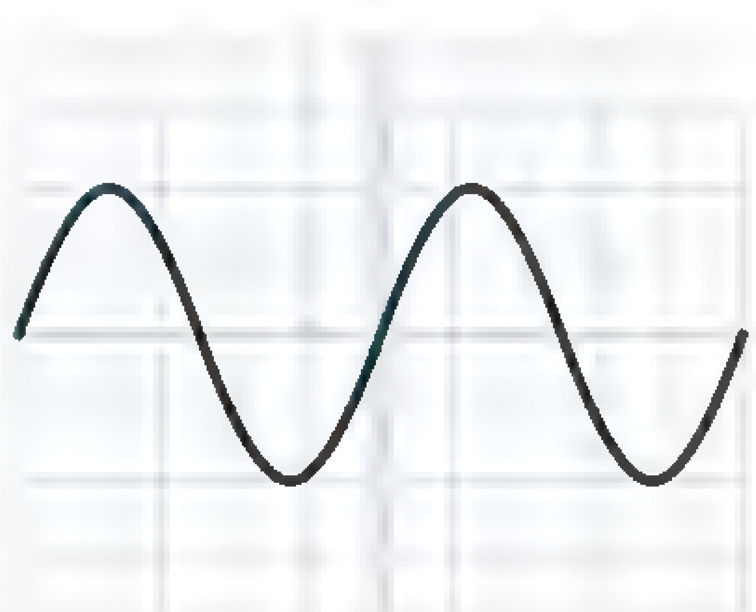


figure 10 Julia's oscilloscope trace.

9 Calculate:

a Calculate the period of a vibration with a frequency of 50 Hz.
b On a tuning fork, it says '440 Hz'. Calculate the vibration period of this tuning fork in milliseconds.
c Calculate the frequency of a vibration with a vibration period of 50 ms.
d A high-pitched beep has a vibration period of 0.25 ms. Calculate the frequency in kilohertz.

10 A DJ uses an equalizer during his DJ set. You can use that to control the volumes of various frequencies relative to one another. This lets the DJ make some frequencies stand out, for instance, making the sound clear and transparent. An equalizer can best be compared to a volume control. You use a normal volume control to adjust the volume of all frequencies at once, but with an equalizer you can control the volume of specific frequencies separately (figure 11).

a What are the frequency ranges for the bass and treble?
b Which frequencies can the DJ reduce the volume of a bit if the music is too shrill?
c Are there also frequencies that the DJ can increase in volume if the music is too shrill?
d In a studio, the equalizer is sometimes used to remove undesired frequencies from sounds or to amplify desired sounds.
Why are the low frequencies of voice recordings often 'cut away' in a studio?

figure 11 Frequencies of music tones.

★ 11 Kursat has attached a needle to a tuning fork. He then strikes the tuning fork and pulls the needle along a glass slide covered in lampblack. Figure 12 shows part of the slide at its actual size. The wave trace is 6.3 cm long. The frequency of the tuning fork is 80 Hz.

a How many vibrations can be seen on the slide?
b How long did it take to draw this wave trace?
c Work out the speed at which the tuning fork was drawn across the glass.

figure 12 The wave trace of a tuning fork.

Test what you know with *Test yourself*.

EXTRA ULTRASOUND AND INFRASOUND

12 Figure 13 shows the frequency range for the hearing of humans and various other animals.

a Which animals can hear the highest tones?

b Which animal can hear the lowest tones?
porpoise / dog / human / crocodile / robin / bat

c A dog whistle makes a sound that a dog can hear but a human can't.
What is the minimum frequency for a dog whistle?

d Are there also tones that a human can hear but a dog cannot? If so, which frequencies are they?

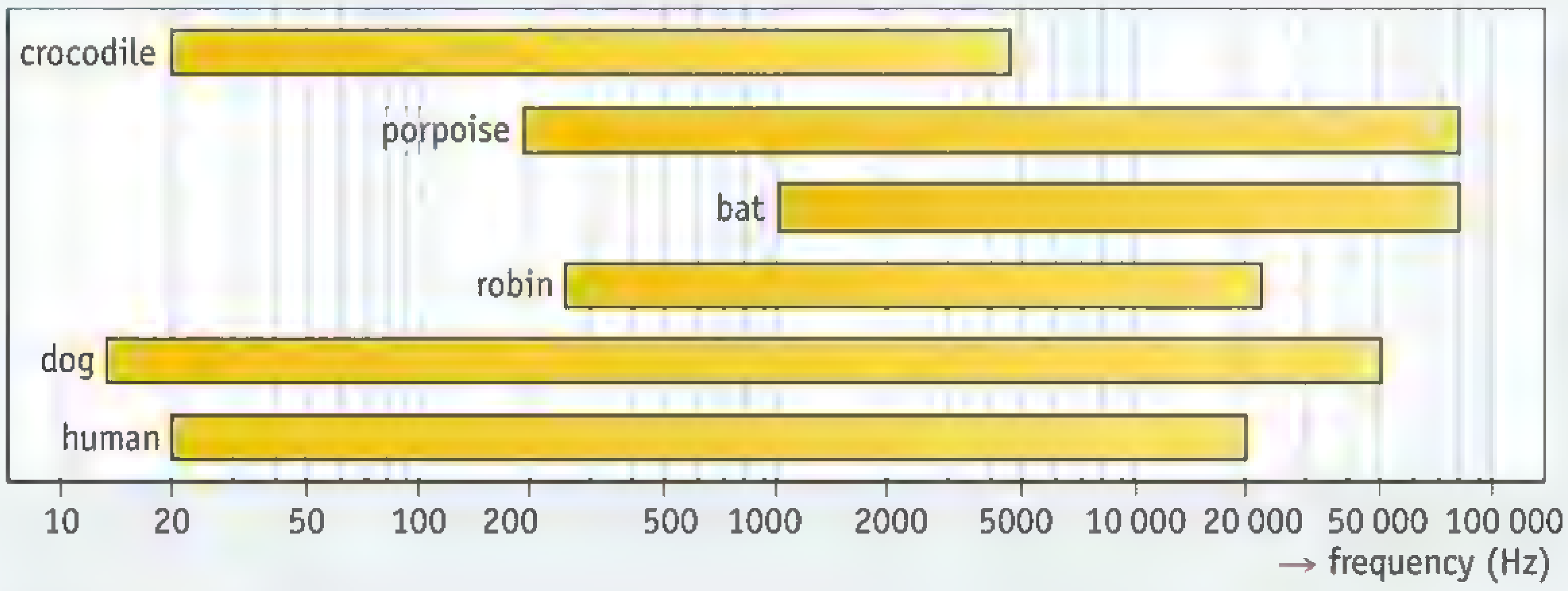


figure 13 The frequency ranges of human hearing and of a number of animals.

13 Ultrasound is used to measure the thickness of the lens in an eye. A device that emits ultrasound is placed in front of the eye. Have a look at figure 14. The ultrasound is reflected back as an echo by each part of the eye. The echoes can be seen on a screen (figure 15). Figure 15 also gives the times between emitting the sound (at time 0) and receiving the echoes.

a How long does it take before the echo is received from the front of the lens of the eye?

b Sound moves through the eye's lens at a speed of 1500 m/s.
Calculate the thickness of the lens.

c Kerry notices that the strength of the reflected sound from the front of the lens is less than for the cornea. From the back of the lens, the sound intensity is even lower.
Explain why.

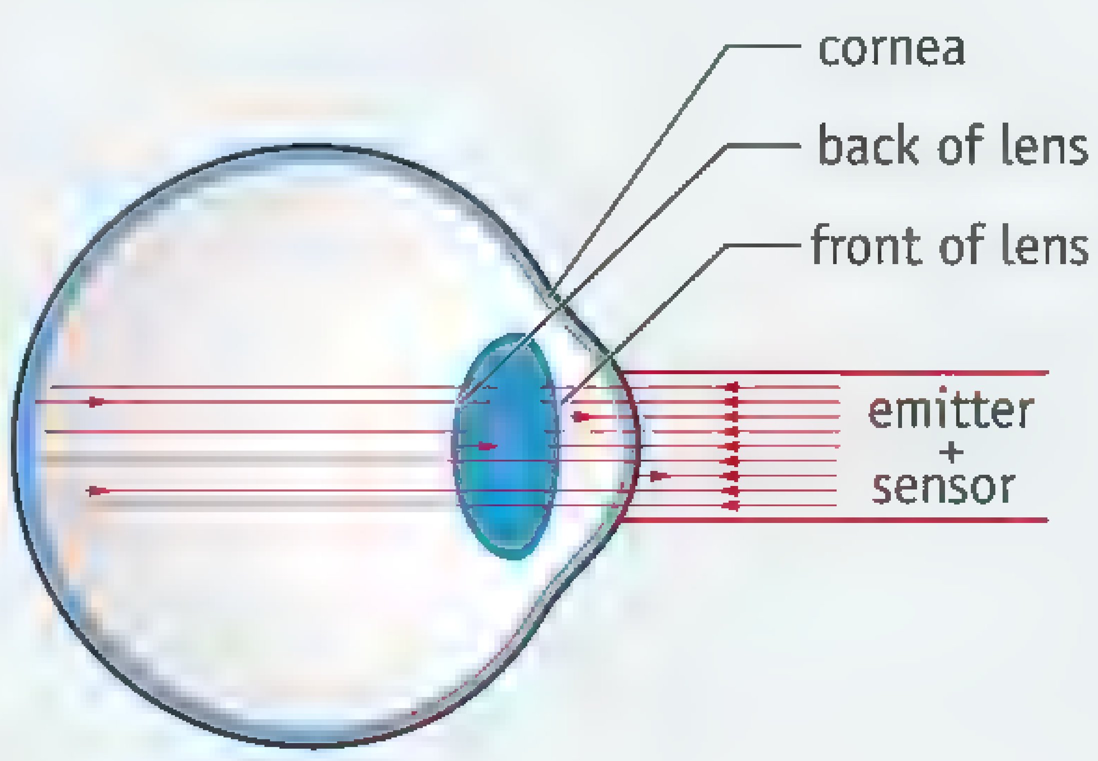


figure 14 An ultrasonic measuring device for your eyes.

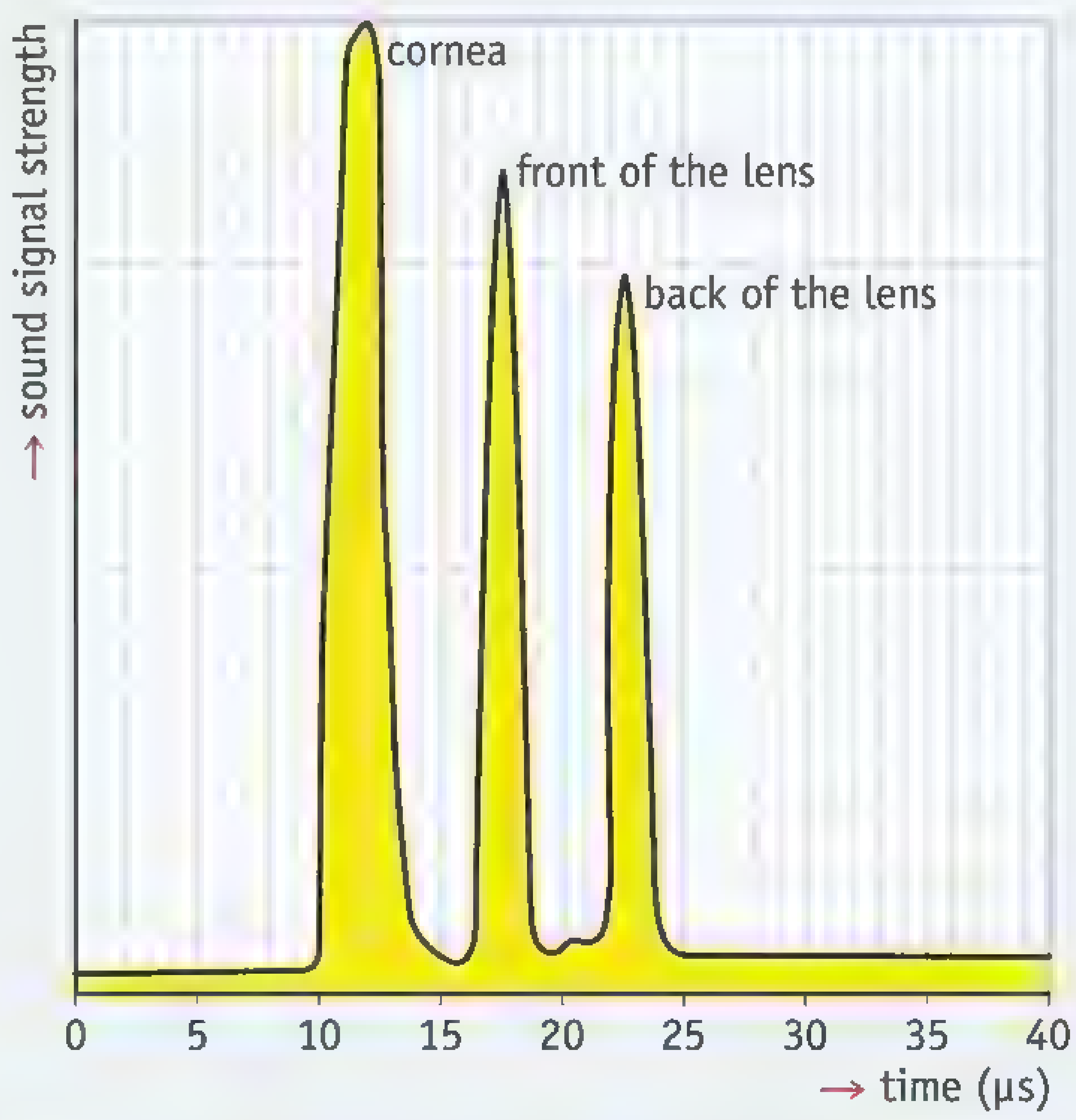


figure 15 The signal strengths of the reflected sounds.

3 Sound levels

LEARNING OBJECTIVES

8.3.1 You can use a graph to explain the relationship between the sound intensity and the amplitude of a vibration.

8.3.2 You can explain how the sound intensity depends on the distance to the sound source.

8.3.3 You can describe how the threshold of hearing and the pain threshold depend on the frequency.

8.3.4 You can explain the difference between the dB(A) scale and the dB scale.

8.3.5 You can do calculations using the relationship between the sound intensity and the number of sound sources.

EXTRA 8.3.6 You can explain how an audiogram is made.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES						
	8.3.1	8.3.2	8.3.3	8.3.4	8.3.5	8.3.6	8.2.2*
Remembering	1ab		1cd	2abcd			
Understanding	3b, 4a	5abc	6abcd, 10b			11cd, 12a	3a
Using	4b				7ab, 8	11ab, 12b	
Analysing			10a		9, 10c		

* You can find this learning objective in an earlier section.

Noises can be so loud that you feel them as well as hear them. The sound at a concert can sometimes be at a high enough volume that you can literally feel it. The bass notes in particular can resonate in your stomach.

THE AMPLITUDE OF A VIBRATION

The *Amen break* is a sample (a short music clip) that is used in a lot of hip hop music. The sample is a bit longer than five seconds and has alternating loud and less loud drum beats. Figure 1 shows how a computer represents this sample. The **sound intensity** indicates how loud the sound produced by the sound source is.

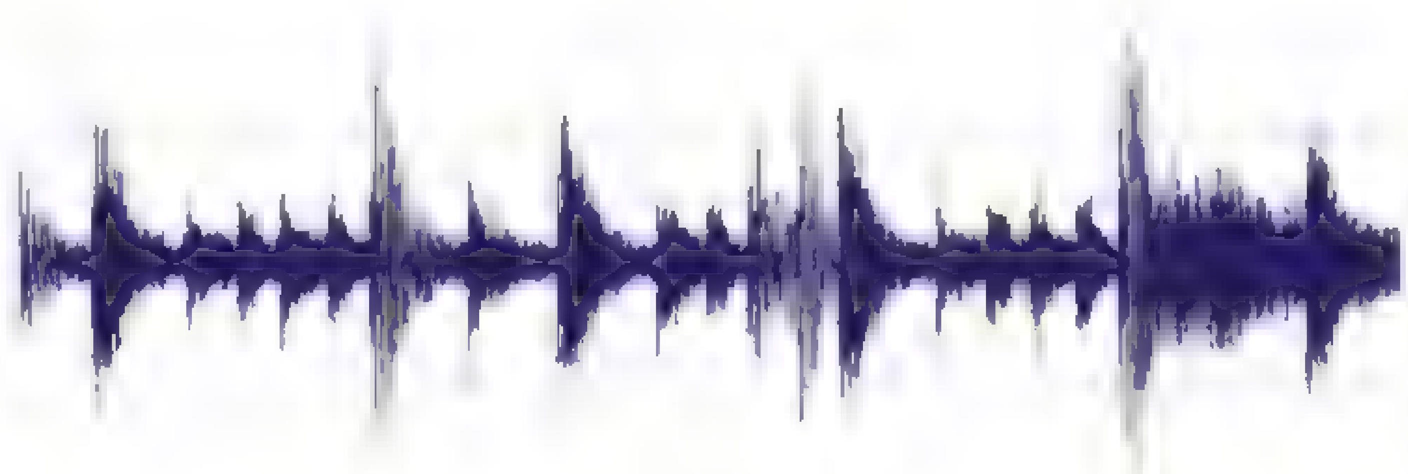


figure 1 The *Amen break*.

When a woofer (bass loudspeaker) is producing the sound of a bass drum, you can see the cone vibrate. This vibration becomes more vigorous when the volume is turned up. This also makes the pressure differences in the surrounding air greater, making the sound louder.

You can use an oscilloscope for investigating the pressure differences. In figure 2, have a look at the distance between the centre of the vibrations and their maximum position. This is called the **amplitude** of the vibrations: the maximum displacement from the centre position (figure 3).

figure 2 A loud tone and a quiet one: the amplitude is shown by a double-headed arrow.

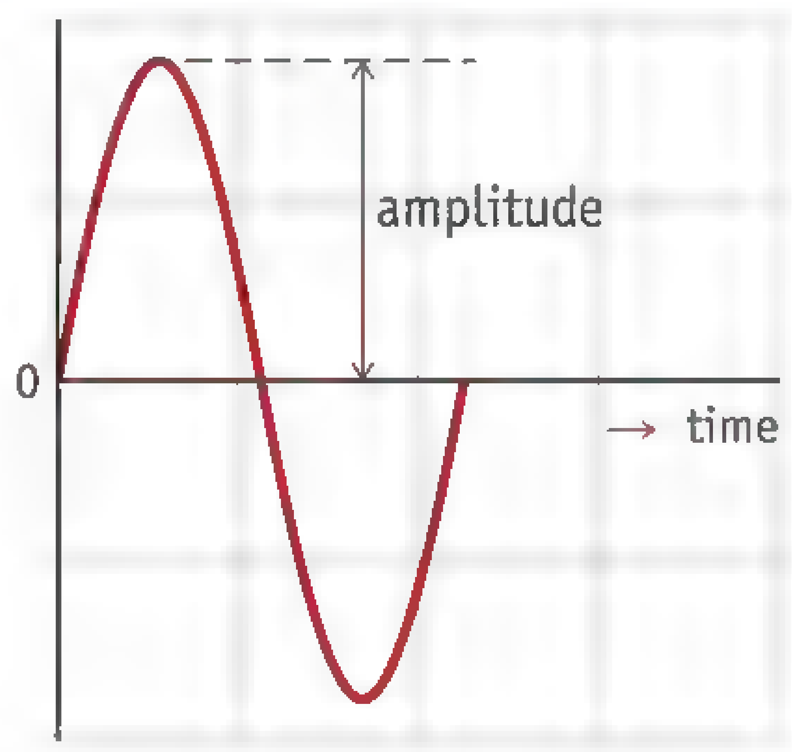


figure 3 The amplitude.

The sound intensity is determined by the amplitude. The louder a sound, the greater the amplitude. When the sound has died away, the amplitude is zero.

THE DECIBEL SCALE

The unit of sound intensity is the decibel (dB). Table 1 shows you the sound intensity (sound level) in various situations. A tone with a frequency of 1000 Hz and a sound intensity of 0 dB cannot be heard (or it may just be audible if your hearing is very good). So 0 dB does not mean that there is no sound at all. The device that you can use to measure sound intensity is called a sound level meter or a **decibel meter** (figure 4). There are also apps for your phone which you can for example use to measure the number of decibels at a music festival.

table 1 Noise levels in various situations.

example	sound intensity (dB)
pain threshold: a jet engine at 25 m	140
jet aircraft starting up at 50 m	130
car horn at 2 m	120
concrete drill at 1 m	110
helicopter at 30 m	100
passing train at 25 m	90
passing moped at 7.5 m	80
vacuum cleaner at 1 m	70
class working	60
residential street in the daytime	50
refrigerator at 1 m	40
pupil whispering	30
rustling leaves	20
pupil breathing	10
limit of detection	0

figure 4 A decibel meter.

An electric moped makes a lot less noise than one that runs on petrol. You can use a decibel meter to determine how much noise a moped with a combustion engine is making. For this measurement, the sound level has to be measured at a fixed distance from the exhaust pipe. This is necessary because the sound intensity varies with the distance from the sound source: you will measure a higher sound level 20 cm from the exhaust than at 80 cm.

THE LIMIT OF HEARING AND THE PAIN THRESHOLD

Our ears are not equally sensitive to all frequencies. That can be seen in figure 5. The **limit of hearing** has been drawn in on this graph. This is the threshold level at which you are just beginning to be able to detect the sound. As you can see, the limit of detection for hearing is greater than 0 dB for many frequencies.

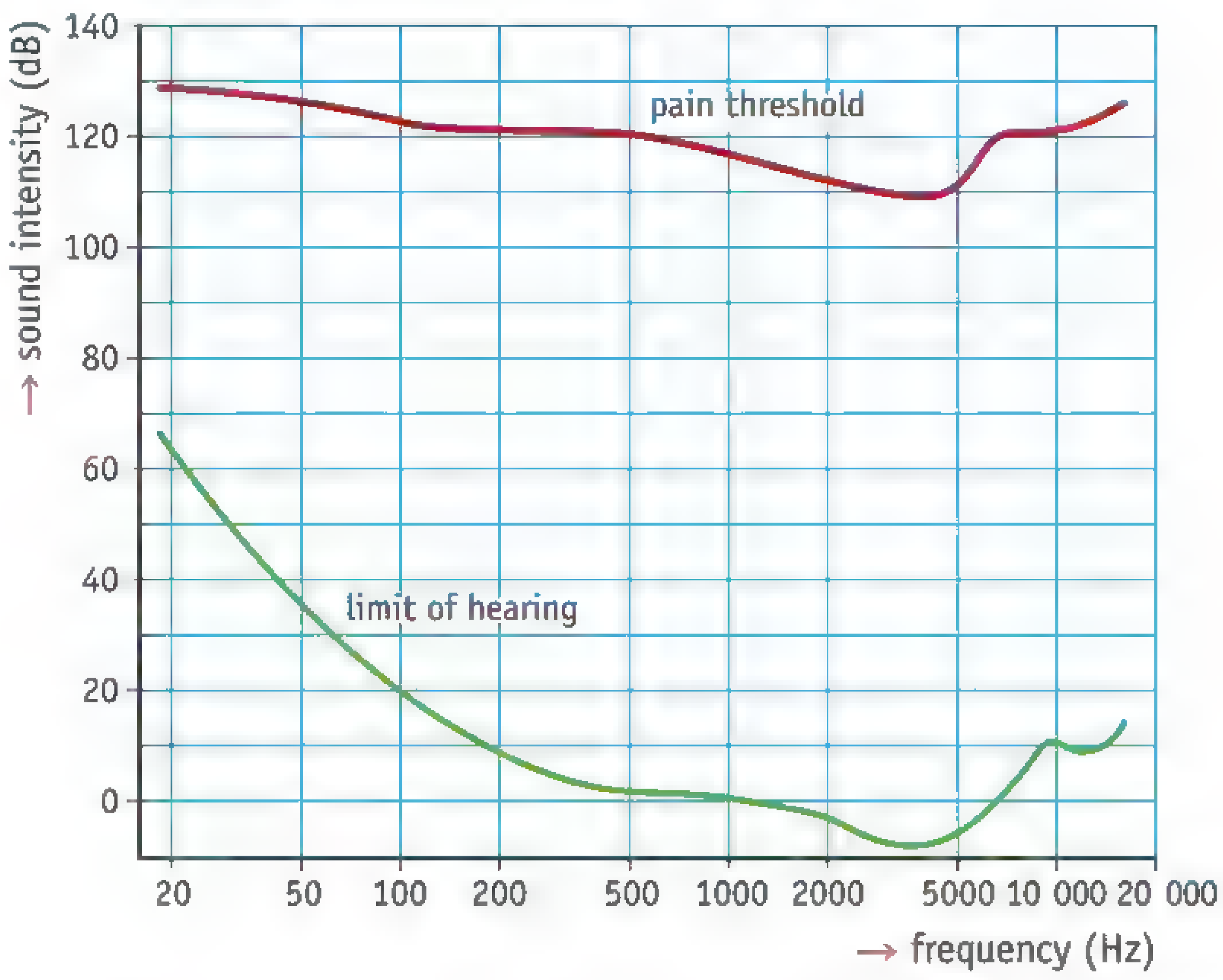


figure 5 The pain threshold and the limit of hearing.

The graph shows that your hearing is most sensitive to tones in the middle of your frequency range, around 4000 Hz. Your hearing is nowhere near as acute for high and very low tones. This makes tones in those ranges seem less loud than they really are. The **pain threshold** – the sound intensity at which your ears start to hurt – is not the same for all frequencies either.

Because your ears are not equally sensitive at all frequencies, most decibel meters have an **A filter.** This adds a profile or contour to the meter's response, giving a lower weighting to very high and low frequencies. This allows the meter to approximate the sound intensities as we perceive them with our ears. If you use the A contour filter, you have to state the sound level in dB(A).

There is virtually no difference between the dB scale and the dB(A) scale at frequencies from 500 to 10,000 Hz. These are the frequencies at which your ears are most sensitive. These are also the frequencies that are most important for being able to understand speech. But for low and very high tones, the sound level in dB(A) is less than the sound level in dB. Measurements that are made to determine noise nuisance always use the dB(A) scale.

CALCULATING WITH DECIBELS

If you double the number of sound sources, the sound does not seem twice as loud. You can see that if you measure the sound intensity in your school's music room. When one pupil is singing, the sound intensity will be somewhere around 55 dB. But if 32 pupils are all singing at once, the (average) sound intensity will not be 32 times as high. You 'only' measure an average sound intensity of 70 dB.

The decibel scale is designed to match the way humans perceive sound. If the number of sound sources is doubled, the power that all the sound sources emit together goes up by a factor of two. But your perception is that this only gives a modest increase in the quantity of noise. On the decibel scale, this is a step of just 3 dB.

So the sound level in decibels can be worked out using the following calculation rule:

> If the number of sound sources doubles, the sound level increases by 3 dB.

However, you can only use this rule if all the sound sources are (roughly) equally loud and (roughly) equally far away.

EXAMPLE EXERCISE 1

The sound level is measured 10 m away from a concert stage (figure 6). If just one violin is playing, the sound intensity is 70 dB. What sound intensity would be measured if a group of eight violins were playing?

The number of decibels is:

- for a single violinist: 70 dB;
- for two violinists: 70 + 3 = 73 dB (from 1 to 2 is the first doubling);
- for four violinists: 73 + 3 = 76 dB (from 2 to 4 is the second doubling);
- for eight violinists: 76 + 3 = 79 dB (from 4 to 8 is the third doubling).

If eight violinists are playing, you therefore measure a sound level of roughly 79 dB.

figure 6 The sound intensity increases in steps of 3 dB.

Practice the concepts using the *Flash cards*.

EXTRA AUDIOGRAMS

If a doctor suspects that your hearing is damaged, he can have your hearing tested by an audiologist. The result of the test is recorded in an audiogram: a graph showing you what your hearing is like, compared to normal hearing. In general, a separate audiogram is made for each ear.

The test involves getting you to listen to a tone (for example 250 Hz) through headphones. The tone is inaudibly quiet at first but then gets louder. You give a signal to the audiologist when you can hear the tone. This determines your threshold of hearing for a 250 Hz tone, in other words the sound level at which you can just hear the tone. The same is then done for several other frequencies.

Figure 7 shows you an audiogram that has been produced using a series of such measurements. The graph shows you the difference between your threshold of hearing and that of someone with normal hearing. If the graph follows the green zero line, then you have perfectly normal hearing. Small deviations from the zero line are very common and do not mean there is any problem, but the differences are larger if your hearing is damaged. The audiogram in figure 7 is for someone who does not hear high tones well. For those tones, the discrepancy is up to 50 dB.

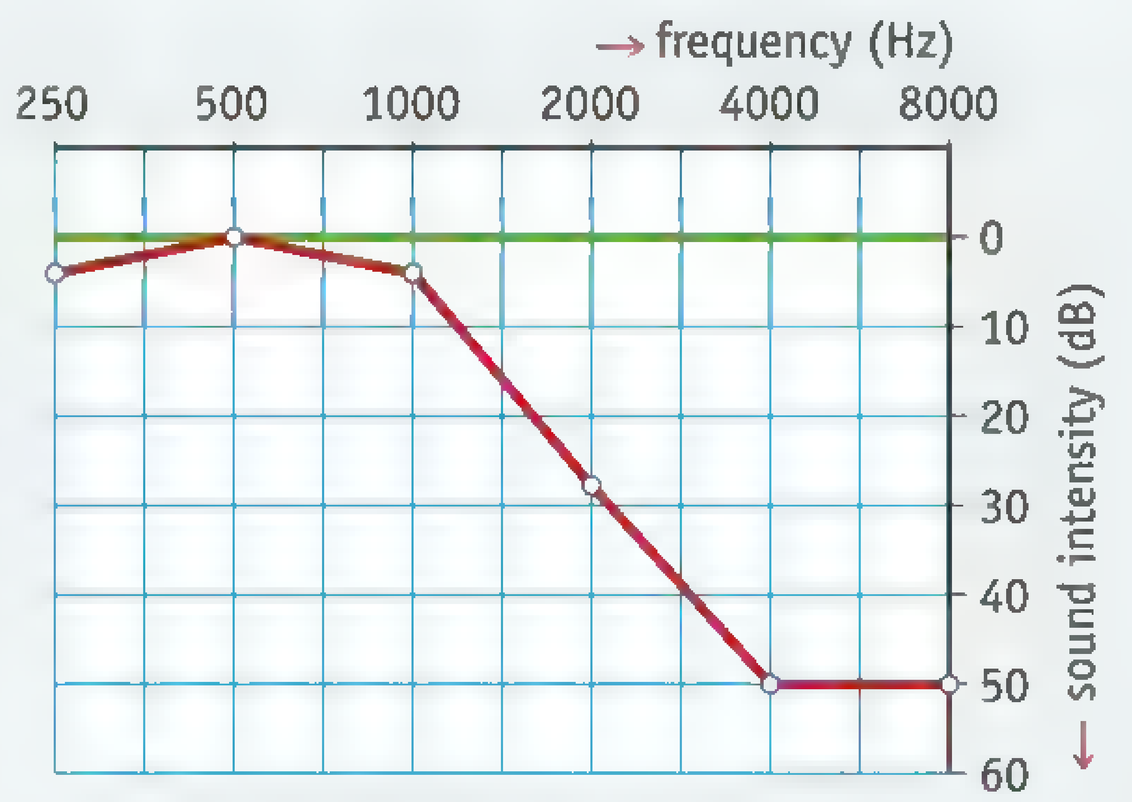


figure 7 This audiogram shows a hearing loss of up to 50 dB for the higher tones.

COURSE MATERIAL

1 Answer the following questions.
- a What units do you use for sound levels?
- b What is the name of the device that you can use to measure sound levels?
- c What is the threshold of hearing?
- d For which frequencies is the threshold of hearing greater than 0 dB?

2 The dB(A) scale is often used instead of the dB scale.
- a What is the name of the filter that is used for this?
- b Which tones do the contours of this filter weaken?
- c Why are these tones weakened?
- d When is the dB(A) scale used?

IN PRACTICE

3

Dimitri plays a note on the piano. He hears a tone that gradually attenuates (fades away).

a Does the frequency of the sound vibration change as the tone becomes quieter? If so, how does it change?

b Does the amplitude of the sound vibration change as the tone becomes quieter? If so, how does it change?

4

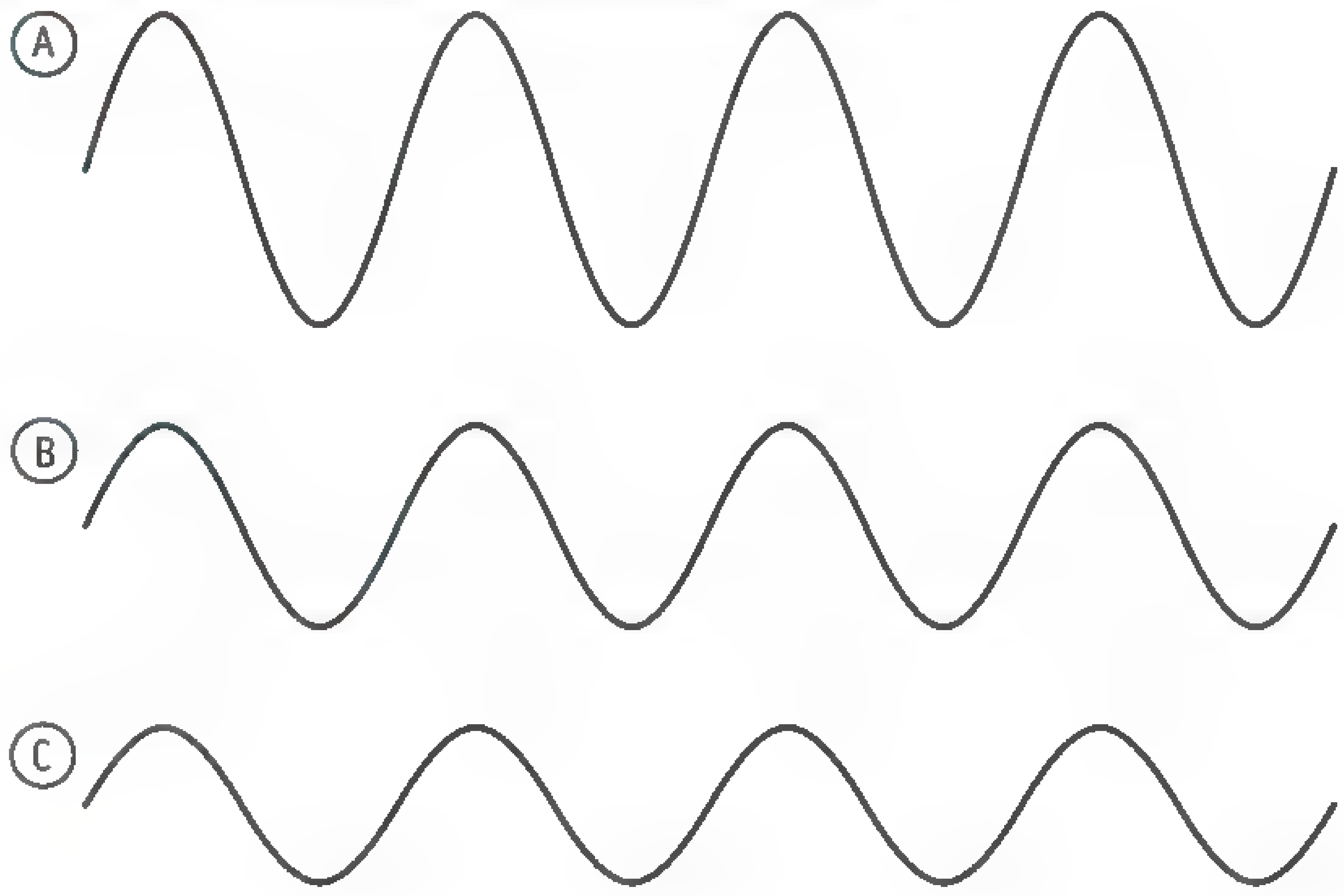
Carol strikes a tuning fork. She then pulls a stylus that has been attached to the tuning fork across a sheet of glass that has been coated with lamp black. Figure 8 shows three sections of the sound trace that it leaves, at 10 × magnification.

a What is the amplitude at A? At B? At C?

b The section of the wave trace at A was produced earlier than the section of the wave trace at B.

How can you see that?

figure 8 Three sections of Carol's wave trace.



5

A police officer is checking whether the motor is making too much noise. When doing this, she holds the decibel meter 50 cm from the exhaust.

a Explain why the sound intensity always has to be measured at a fixed distance from the sound source.

b What goes wrong if the distance between the decibel meter and the exhaust is greater than 50 cm?

c What goes wrong if the distance is less than 50 cm?

6

Have a look at figure 5.

a A tone has an intensity of 20 dB and its frequency is 50 Hz.

Can you hear that tone?

b A tone has an intensity of 20 dB and its frequency is 5000 Hz.

Can you hear that tone?

c What is the minimum sound level for a tone of 100 Hz if you are to be able to hear it?

d What is the minimum sound level for a tone of 10,000 Hz if you are to be able to hear it?

7

Danny, Eugenie, Amber and Thomas are a trumpet quartet. During a concert, Eugenie plays a solo. A sound intensity of 74 dB is measured 5 m away from her trumpet.

a Danny, Amber and Thomas join in. All four of them play the same piece of music on their trumpets.

What is the sound level 5 m away from the four trumpets?

b Danny and Thomas stop playing.

What is the sound intensity now, 5 m away from the two remaining trumpets?

8 The sound level from a piano at a distance of 10 m from a concert stage is 82 dB. A violinist produces a sound intensity of 70 dB at the same distance.
The composer of a piece of music wants the violin part to be as loud as the piano. How many violinists should he have playing?

★ 9 The noise level in a football stadium is measured at the centre of the pitch. When a thousand people are cheering, the decibel meter registers 80 dB.
Give an estimate of the approximate noise level if a hundred thousand people were cheering. Explain how you got your answer.

★ 10 A device produces a buzzing noise with a frequency of 100 Hz. At a distance of 10 m, the intensity of the buzz is 0 dB.

- **a** Using figure 5, what can you say about how many devices there must be if you want to be able to hear the buzzing from 10 m away?
- **b** If the frequency of the noise becomes higher, you are then able to hear it. What frequencies can you just hear if the sound level is 0 dB?
- **c** At a distance of 40 m, sixteen of these devices together give a sound intensity of 0 dB. What is the sound level from a single device at a distance of 40 m?

Test what you know with *Test yourself.*

EXTRA AUDIOGRAMS

11 An audiologist has tested Jack and Billy's hearing. Table 1 shows the results of the investigations.

- **a** Draw Jack's audiogram in figure 9.
- **b** Draw Billy's audiogram in figure 10.
- **c** Whose audiogram is not normal?
- **d** Which tones can he hear less well?

table 1 The results of two hearing tests.

[illegible]	[illegible] in dB	[illegible] in dB
250	2	62
500	0	48
1000	0	25
2000	−2	7
4000	−2	3
8000	0	2

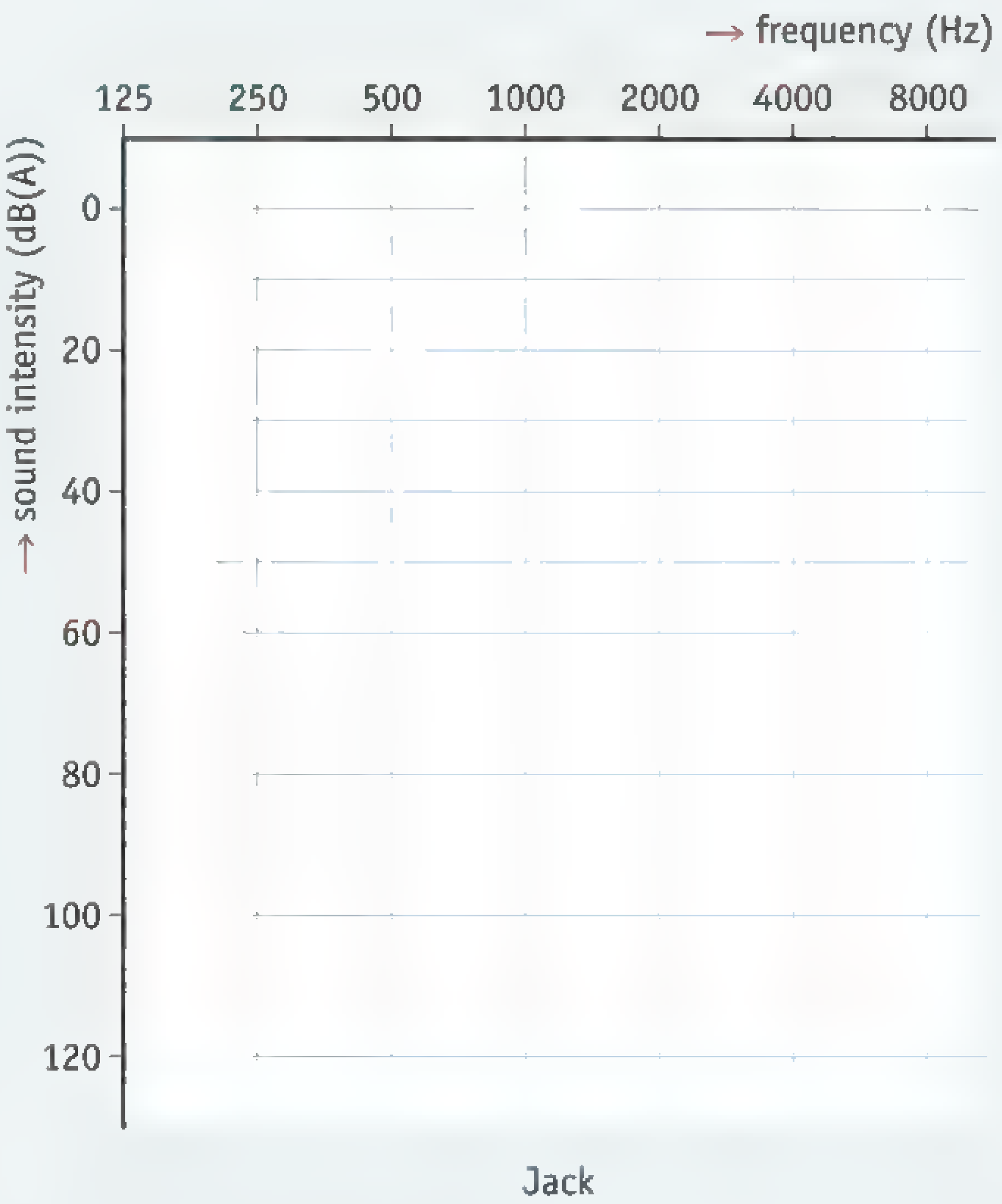


figure 9 Jack's audiogram.

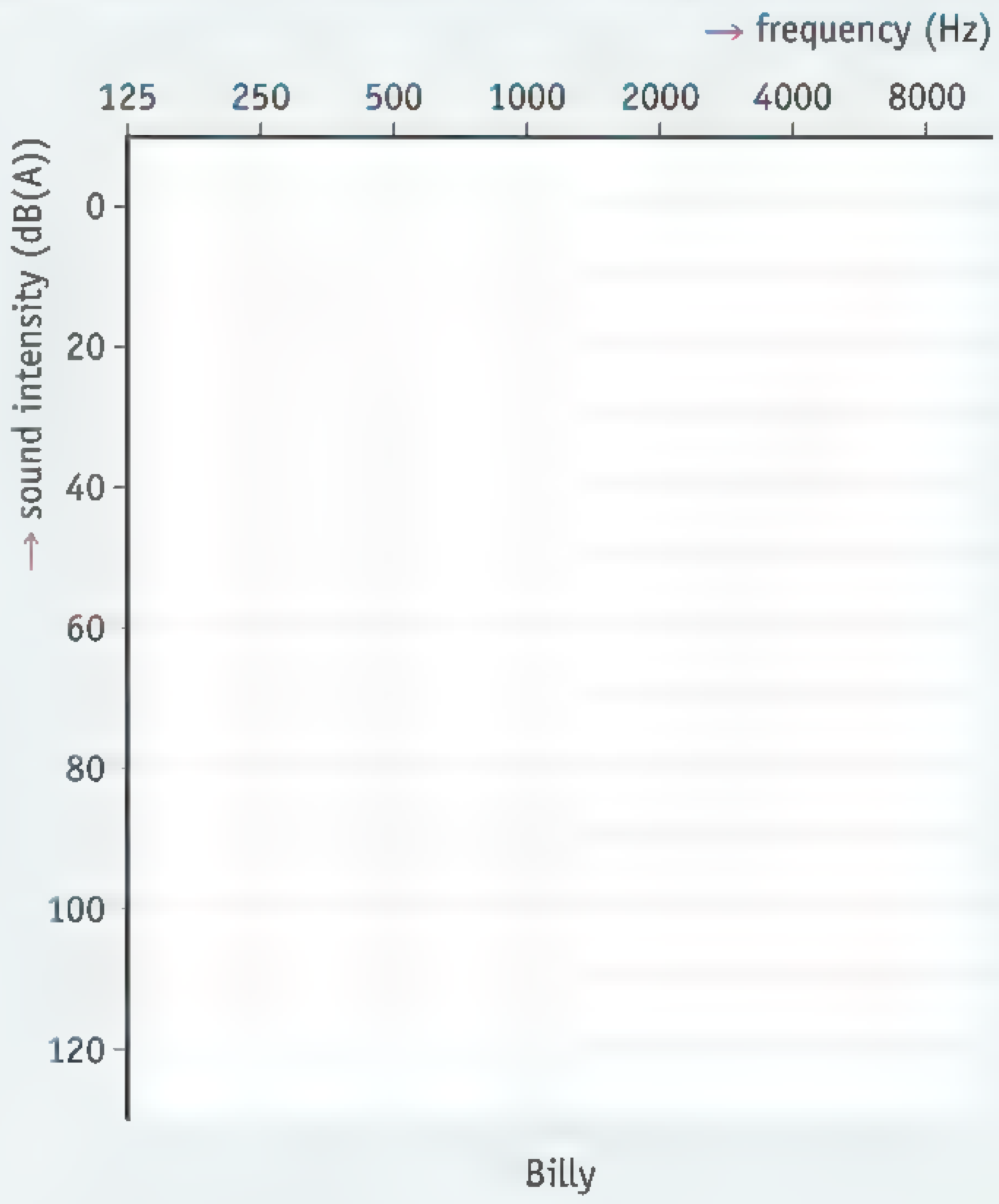


figure 10 Billy's audiogram.

12 Noise-induced hearing loss occurs when your ears have been exposed to noise for too long. Figure 11 shows the audiograms of people in various stages of noise-induced deafness.

a What does hearing damage in stage 3 or 4 mean for listening to music?

b People with hearing damage in stage 3 get a hearing aid.
Sketch a graph in figure 12 showing how the hearing aid should amplify sound. Plot the amplification (in decibels) against the frequency (in hertz).

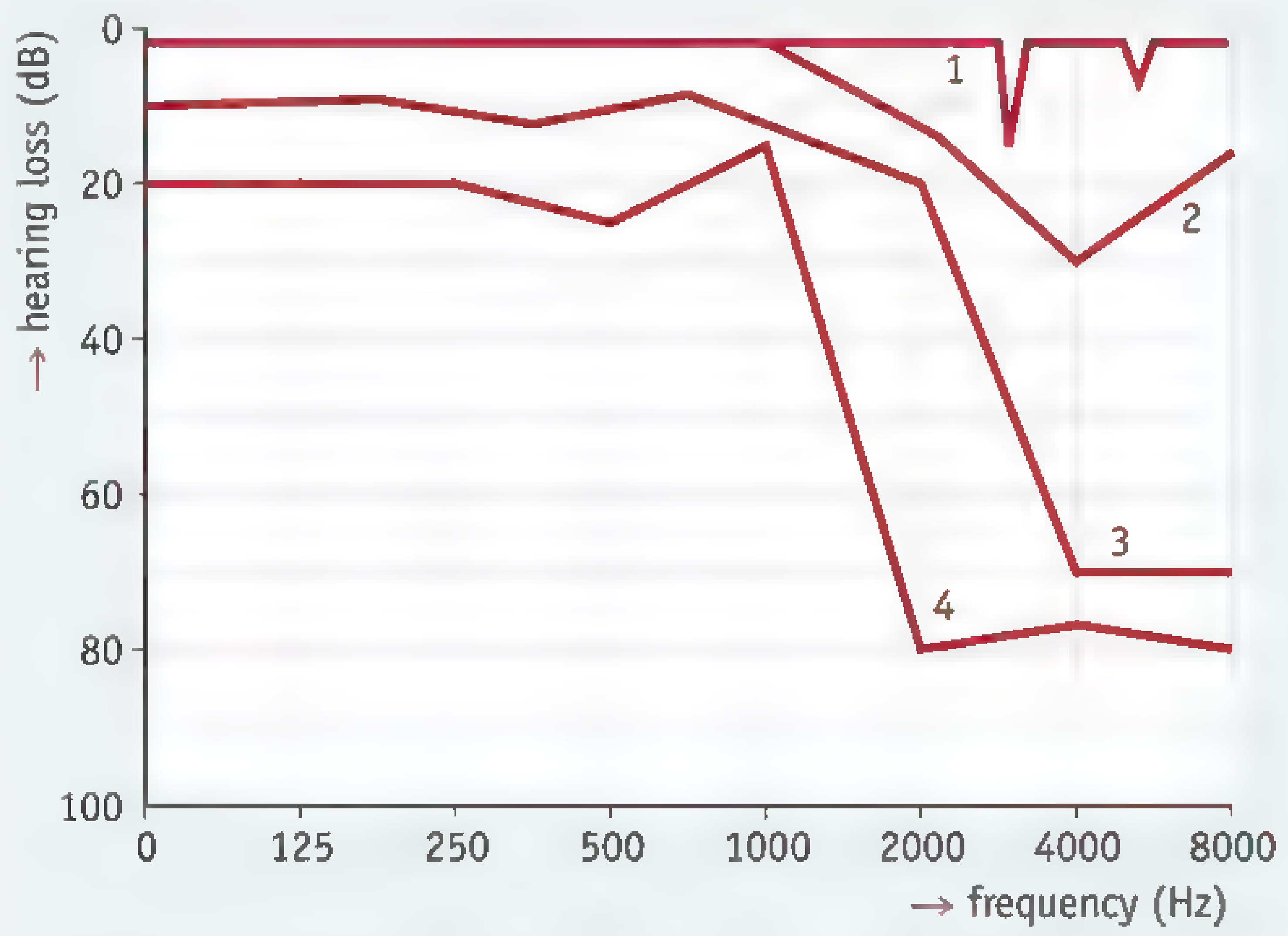


figure 11 Audiograms of people in various stages of noise-induced hearing loss.

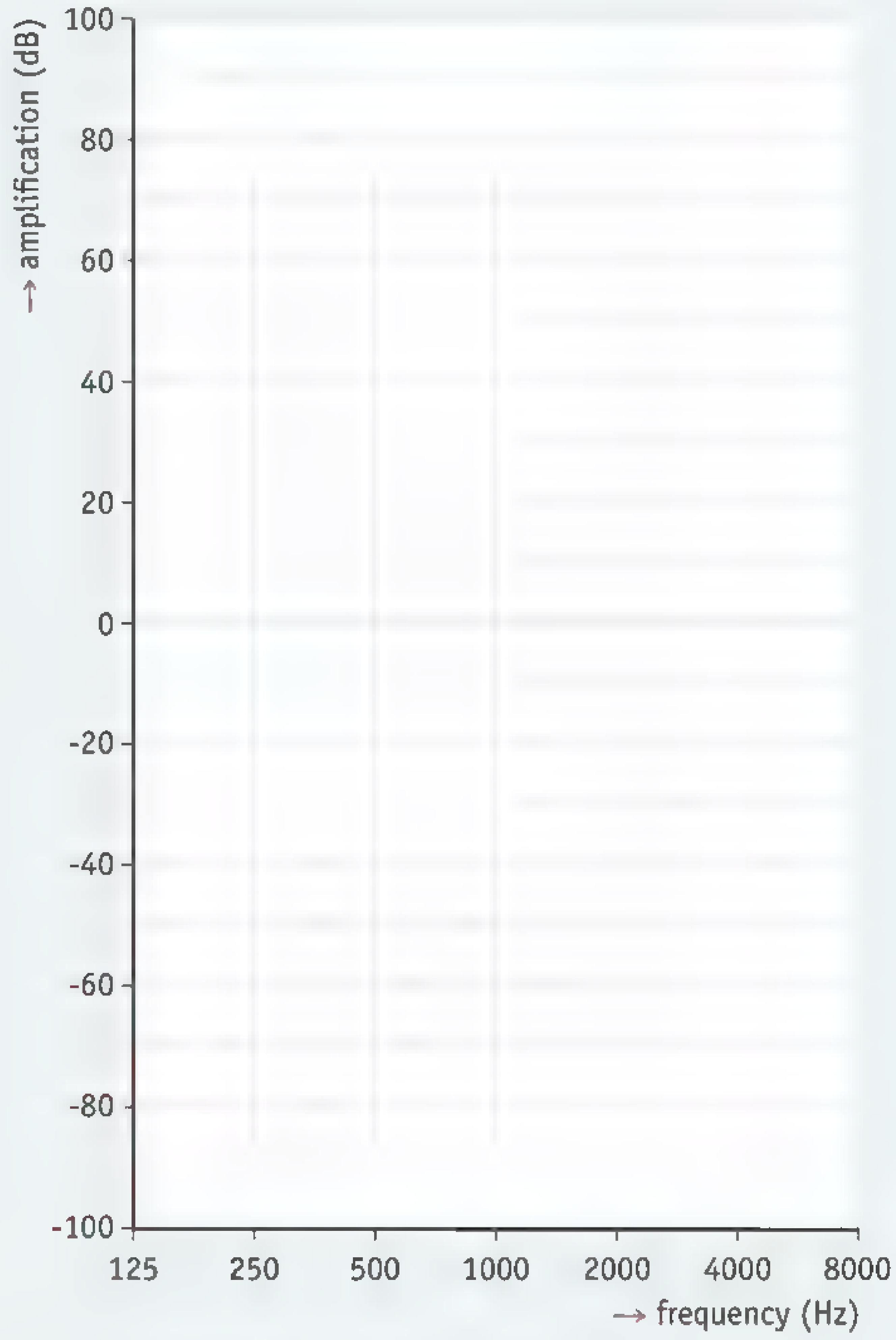


figure 12 Sound amplification by the hearing aid.

4 Combating noise nuisance

LEARNING OBJECTIVES

8.4.1 You can describe which factors determine whether or not noise is harmful for your hearing.
8.4.2 You can also explain why it is so important not to expose your ears to too much loud music.
8.4.3 You can explain the difference between harmful and nuisance noise.
8.4.4 You can explain three ways of combating noise nuisance.
EXTRA 8.4.5 You can explain how noise cancelling works.

TAXONOMY	LEARNING OBJECTIVES AND EXERCISES					
	8.4.1	8.4.2	8.4.3	8.4.4	8.4.5	8.1.3*
Remembering		1abcd		2abc	8b	
Understanding	6ade		6bc	3, 4b	8a	4ac, 5
Using				7ab	9, 10ab	
Analysing					8c, 10c	

* You can find this learning objective in an earlier section.

Noise can be extremely irritating. Think of the sound of a dripping tap or a fork screeching across a plate. Noise nuisance from neighbours is high up the list of things that annoy people most in the Netherlands. Loud noises are also capable of damaging your hearing permanently. All very good reasons for combating unnecessary noise.

HARMFUL SOUND INTENSITIES

Loud noises are bad for your hearing. If the sound levels are up at the pain threshold, your hearing can be damaged almost immediately. Lengthy exposure to noise at 80 to 90 dB can be enough to damage your hearing. Many people underestimate the risk because you do not notice at first that your hearing is deteriorating.

Whether or not noise is harmful for your hearing depends on more than just the intensity. The length of time that you are exposed to the noise plays a part too. Figure 1 shows you the maximum times for which an employee may be exposed to noise. For noise at 80 dB(A), the figure is eight hours; for noise at 83 dB(A) it is four hours; for noise at 86 dB(A) it is two hours, and so forth.

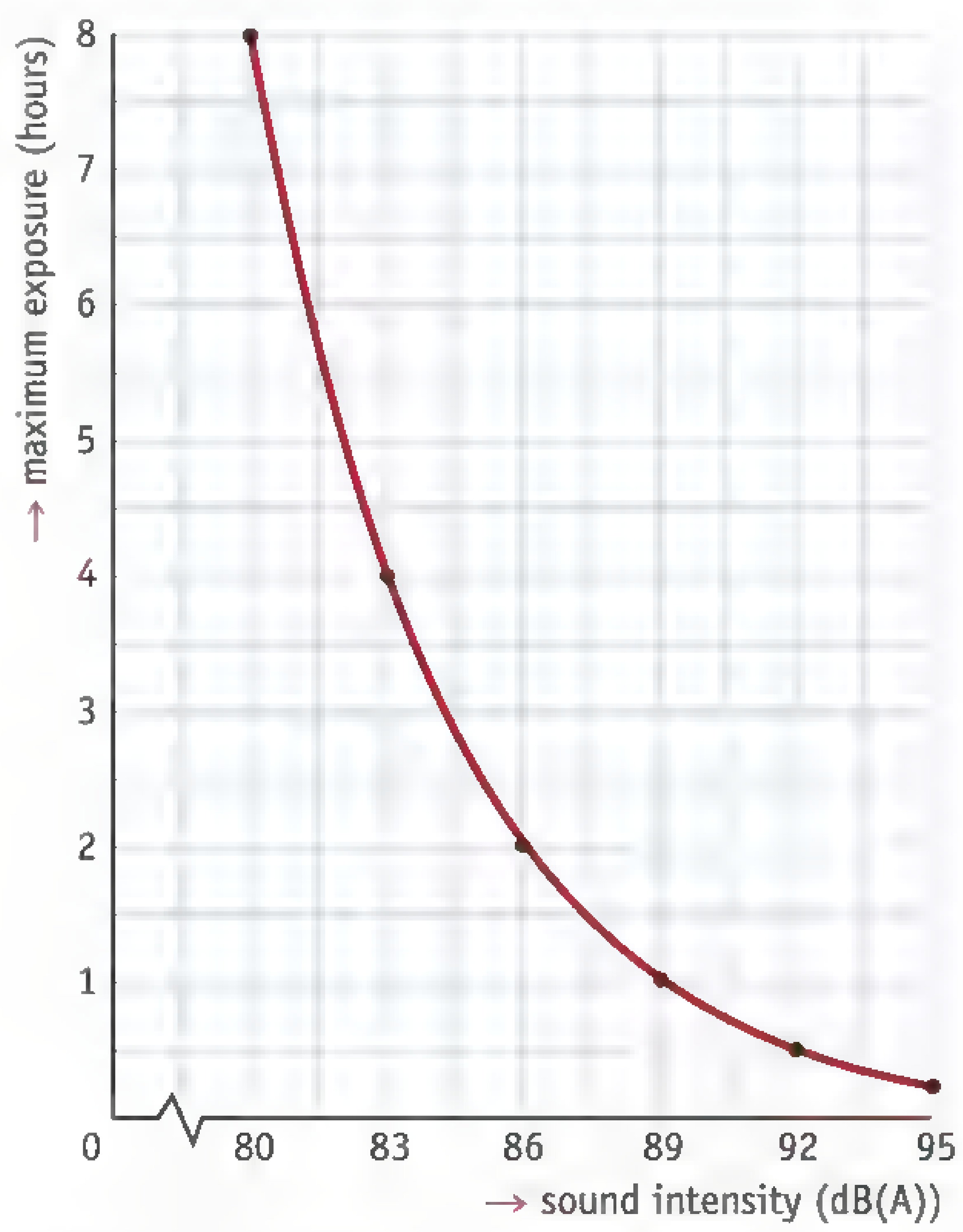


figure 1 The louder the noise, the shorter the time you are allowed to be exposed to it.

Hearing a ringing in your ears, for instance after a concert where you were too close to the speakers, is a sign that your ears were damaged and need to recover. Otherwise you will be risking permanent hearing damage. It can take years before permanent damage becomes noticeable. By the time you are becoming hard of hearing, you are already too late: the damage can then never be reversed.

Hearing damage can take other forms than just deafness. Some people hear continuous sounds that are not present, such as a high beep or ringing or buzzing. They have to learn to ignore that sound or they wear a noise generator that masks the annoying sound. In the Netherlands, over half a million young people aged between 16 and 30 already have permanent hearing damage.

NOISE NUISANCE

Noise that is not harmful can nevertheless be a nuisance. Some people are more affected by particular nuisance sounds than others. Many people get irritated by traffic noise and excessively noisy neighbours.

Whether or not you feel a noise is a nuisance often depends on the situation. A party at the neighbours is not necessarily a problem at all, until you want to go to sleep and realize that the music is in fact pretty loud. Many people are not bothered if others in their train carriage want to talk, but you might prefer to sit in a 'silent' carriage when you want to revise the material for a test. If you want to study quietly, you can also put on headphones that suppress noise from the surroundings (figure 2).

figure 2 Studying in the library.

Noise nuisance that stops people from sleeping properly is more than just an annoyance, though. Lack of sleep causes irritability, poor concentration and fatigue; over the course of time, a lack of sleep can affect your health negatively.

NOISE ABATEMENT MEASURES

A car driving along a road produces quite a bit of noise. There is noise from the engine propelling the vehicle, from the wheels moving over the road surface and from the air flowing past the car. You can also easily hear the brakes when the motorist presses the brake pedal hard.

Various ways have been thought up to reduce traffic noise nuisance. Experts divide these measures into three categories: at the source, between source and receiver, and at the receiver.

At the source

These are measures that lead to the source – the traffic – producing less noise. This might for instance include surfacing motorways with special low-noise asphalt. Since 2016 there have been stricter rules about the amount of noise car tyres may make.

Between the source and the receiver

These are measures in the area between the road and a residential area, such as **noise barriers** (e.g. embankments and screens). Commercial premises are also often built alongside motorways so that they can screen off the residential districts behind them.

At the receiver

These are measures that are taken in residential areas. Houses that are close to a motorway are for instance even more thoroughly insulated against noise. Much less noise then gets inside the houses.

ABSORBING OR REFLECTING SOUND

A thick embankment of earth beside a motorway can dampen traffic noise considerably. The sound is absorbed by this type of barrier: the sound vibrations penetrate the embankment to a certain degree but fade out before getting through to the other side. Materials that are intended to absorb sound are soft and have irregular surfaces.

If there is not enough room for an embankment as a barrier, a screen is often placed alongside the motorway. A screen such as this reflects the sound so that it does not reach the houses and flats by the motorway (figure 3). Materials that are intended to reflect sound are hard and have smooth surfaces.

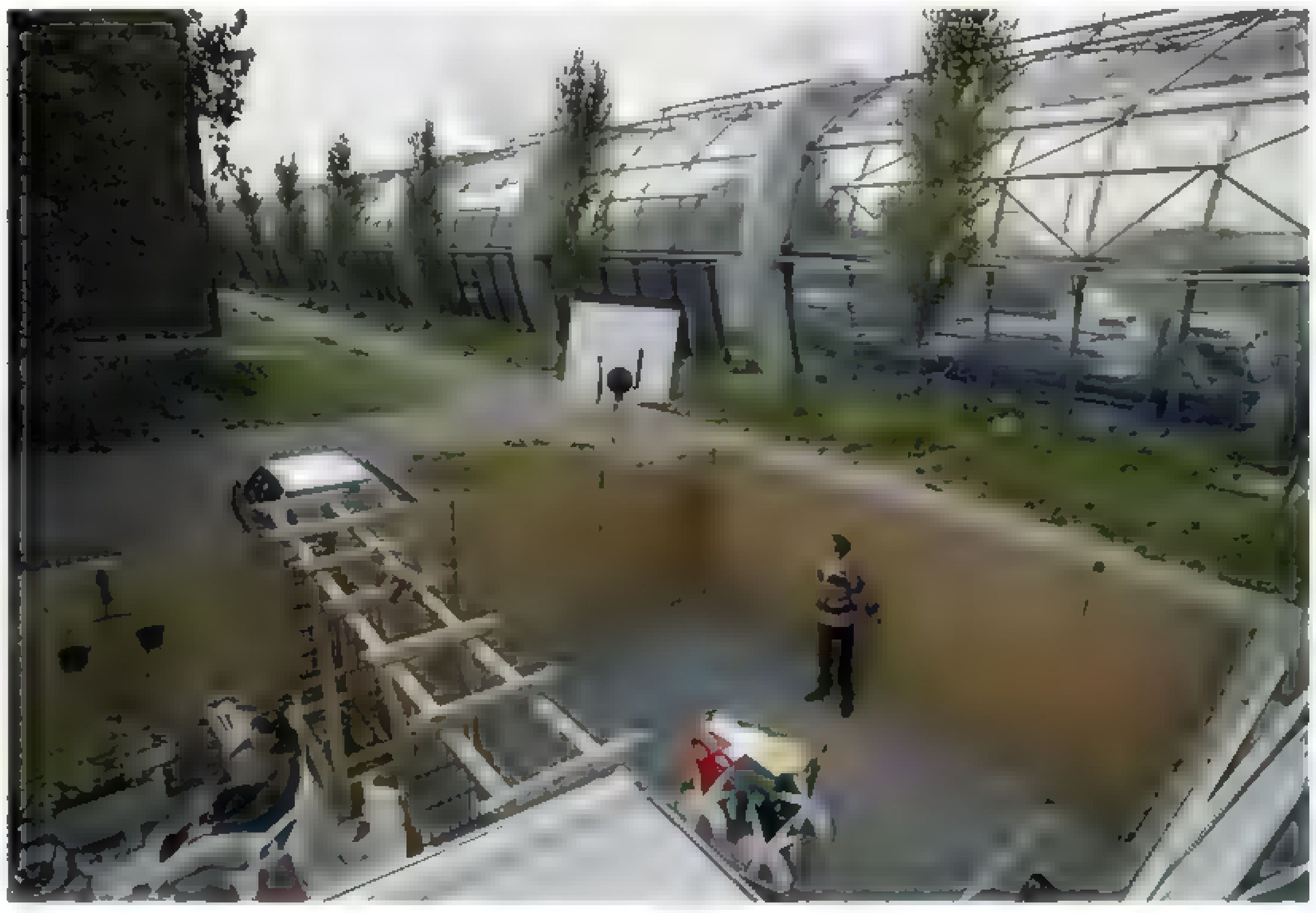


figure 3 A noise screen.

SOUND INSULATION

Noise nuisance can often be combated by **sound insulation.** This is often done using insulation material such as glass wool, which absorbs sound very well. The insulation can be applied at the source of the noise or at the receiver. Both methods are used in practice.

You can insulate a noisy machine by building a properly enclosed casing around it, with a good thick layer of insulating material. The noise vibrations are attenuated substantially by an insulating layer like this. Noisy machines are often fitted with rubber feet underneath. The rubber damps the vibrations so that they are not transmitted to the floor.

Sound insulation can also be applied at the receiver. Employees must for example wear earmuffs or earplugs (figure 4) if the noise levels at their place of work exceed 85 dB(A). This reduces the amount of noise reaching their ears a lot.

figure 4 Earmuffs and earplugs.

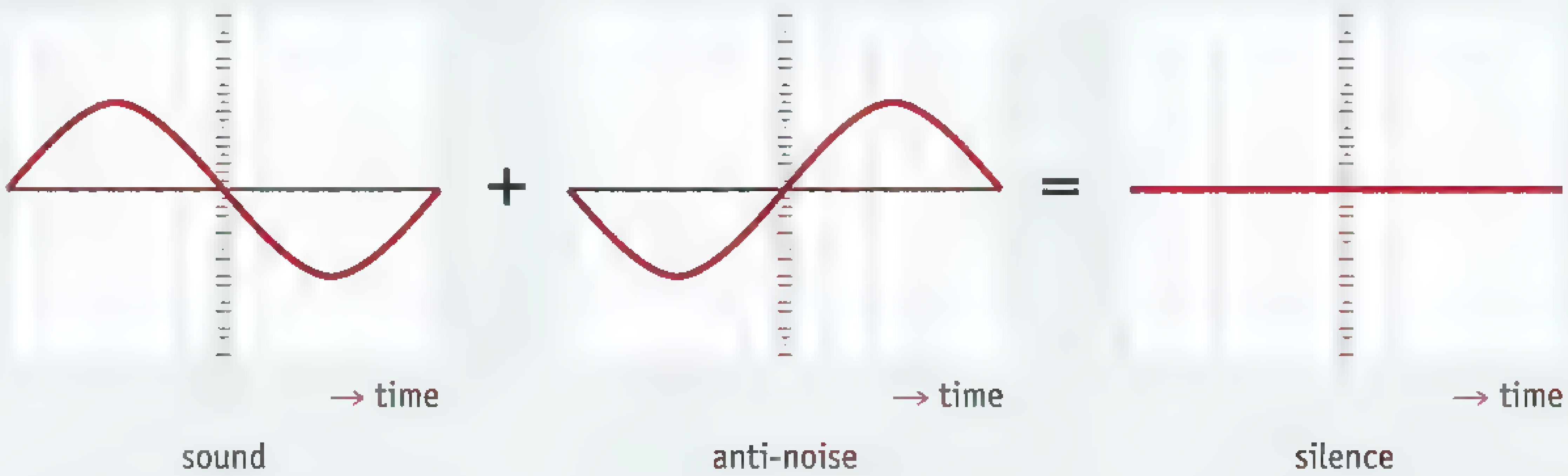
Practice the concepts using the *Flash cards*.

EXTRA NOISE CANCELLING

Noise-cancelling headphones damp down the sounds from the surroundings, letting you hear music or a podcast better than with normal headphones. Headphones like these are quite a bit more expensive than normal headphones and you will also notice that the batteries run down more quickly. This is because they use anti-noise.

Figure 5 shows you how anti-noise works. The graph on the left shows a sound from the surroundings. The headphone then produces a vibration that is the exact opposite. When you add the two graphs together, it always comes out as zero. So the two sounds are cancelling each other out!

figure 5 How anti-noise works.



You can also use noise-cancelling headphones if you need peace and quiet to concentrate. Ambient noise (from the surroundings) is picked up and anti-noise is produced extremely quickly to reduce the noise. That is easy to do for the sound in figure 5 because it is a pure tone involving just a single frequency. Most sound sources produce noise containing all sorts of frequencies at the same time, though. That makes it awkward to produce the correct anti-noise. But the techniques are improving steadily, as long as the sound has a regular pattern. There are cars and planes with anti-noise now too.

COURSE MATERIAL

1

Noise can be a nuisance and it can be damaging.

a When is noise damaging?
b Give an example of damaging noise.
c When is noise a nuisance?
d Give an example of a nuisance noise.

2

The traffic on a busy road can make a lot of noise.
Write down one way of combating traffic noise nuisance:

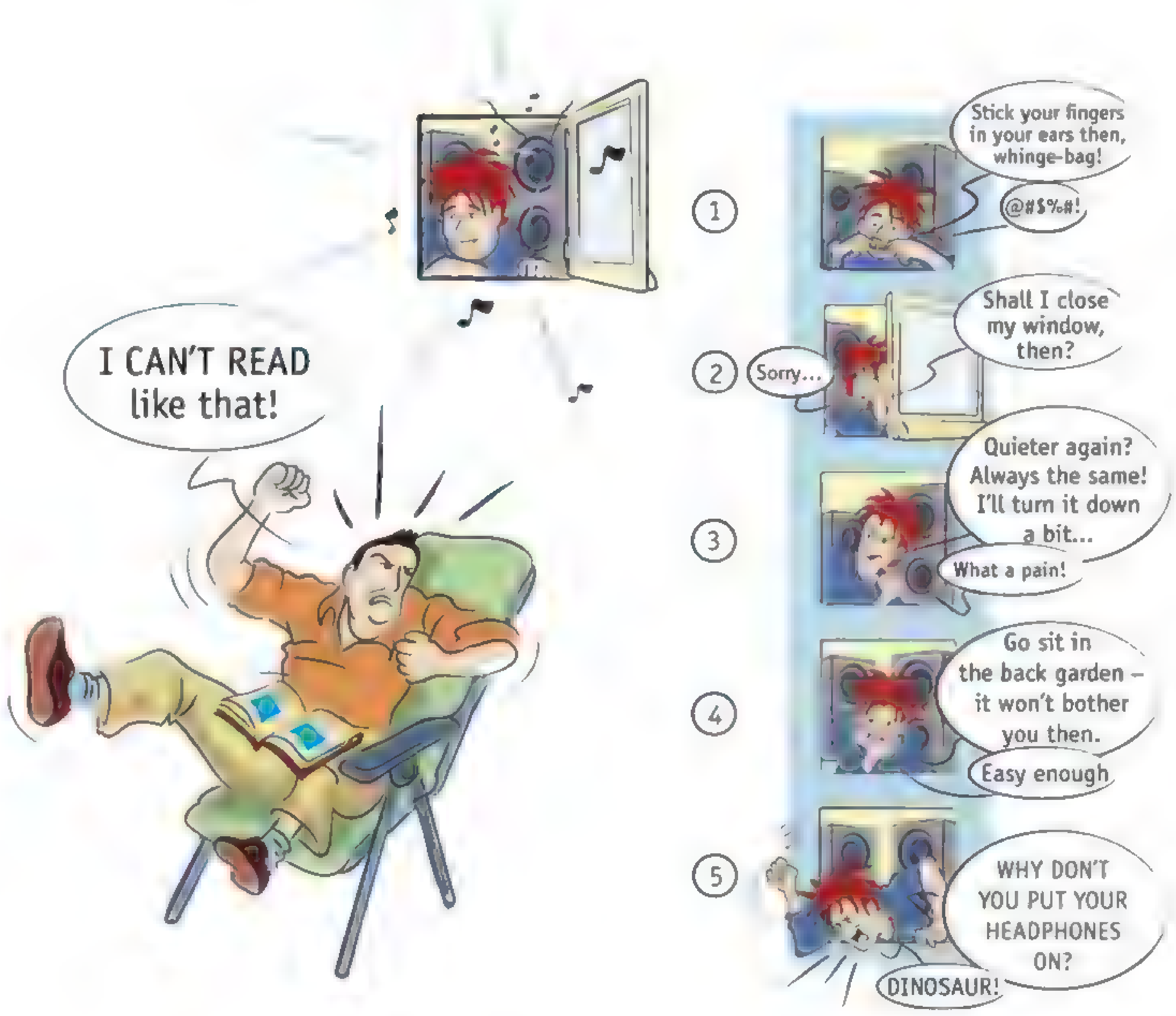
a at the source.
b between the source and the receiver.
c at the receiver.

IN PRACTICE

3

Garfield is complaining about the noise Brad is making. Brad can respond to this in various ways (figure 6).
For each response, state whether the measure is being taken at the source, between the source and the receiver, or at the receiver.

figure 6 Could you turn it down a little?



4

Harry lives on the fifth floor of a block of flats. He is a pianist and he needs to practice several hours a day. When he is playing his piano, the low notes can clearly be heard on the first floor of the apartment block.

a By what route (or routes) does the sound of the piano get down to the first floor?
b Harry's downstairs neighbours asked him to put thick pieces of rubber underneath the feet of his piano.
Why are the downstairs neighbours now less bothered by Harry's piano playing?
c Harry insulates the room that the piano is in.
Why is it better not to have the insulation attached to the wall?

5

A cavity wall consists of an internal wall and an exterior wall. These two walls are often connected together using steel rods called wall ties (figure 7). A cavity wall provides better noise insulation if ties are not used.
Explain why.

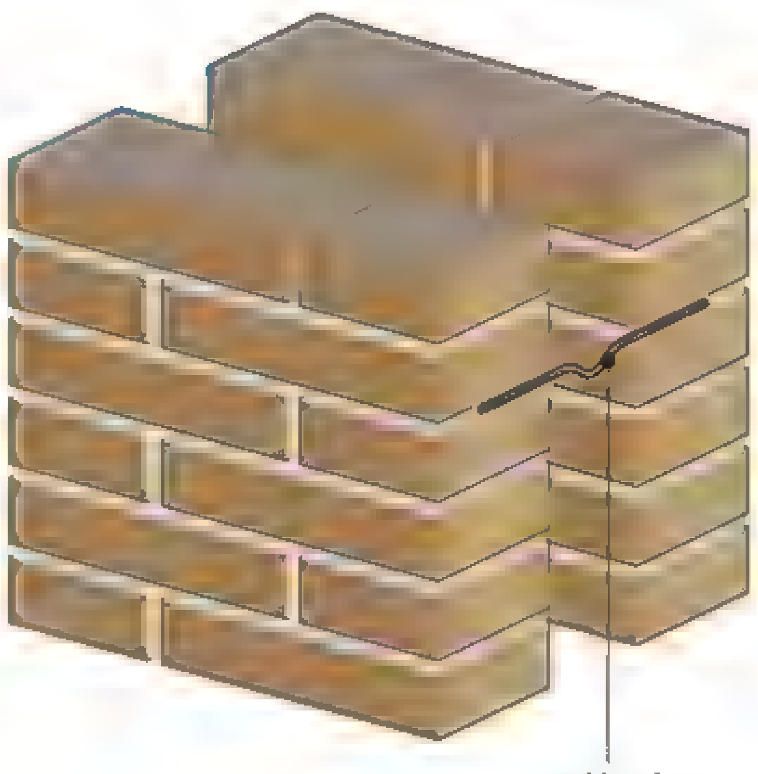


figure 7 Cavity wall with wall ties.

6

Use figure 1 to help answer the questions below.
If you turn the volume of your phone to its maximum, the sound level from the earphones can easily reach 95 dB(A).

a Is a sound intensity of 95 dB(A) bad for your ears? Explain your answer.
b Afzal hears a beep in his ears after listening to music at 95 dB(A).
How long do you think he was listening to it, as a minimum?
c What would you advise Afzal to do?
d Jessie says that she has the earphones of her phone in for about eight hours a day.
What is a safe sound level for someone who listens to that much music?
e Jeremy works in a factory where the noise level is 85 dB.
Is it a good idea for Jeremy to wear ear protection?

7

When designing or renovating factories, the noise nuisance for the workers is taken into account. Machines sometimes make a great deal of noise. One of the ways of tackling that nuisance is building insulating housing around the machinery.

a Think of two disadvantages of limiting the noise nuisance this way.
b The noise nuisance can also be tackled at the receiver. The workers will then have to wear earmuffs or earplugs.
Write down one disadvantage of reducing the noise nuisance at the receivers.

Test what you know with *Test yourself.*

EXTRA NOISE CANCELLING

8 Answer the following questions.

a Explain how noise-cancelling headphones work.

b Explain why the batteries of noise-cancelling headphones run out much more quickly than the batteries of headphones without noise cancelling.

c Noise cancelling works well for low-pitched tones in particular.
Explain why noise cancelling for high-pitched tones is much more difficult.

9 The engines of planes produce an easily predictable sound that is not particularly complex. That is one of the reasons why noise cancelling works well in them.
Why is it important that the sound is easily predictable?

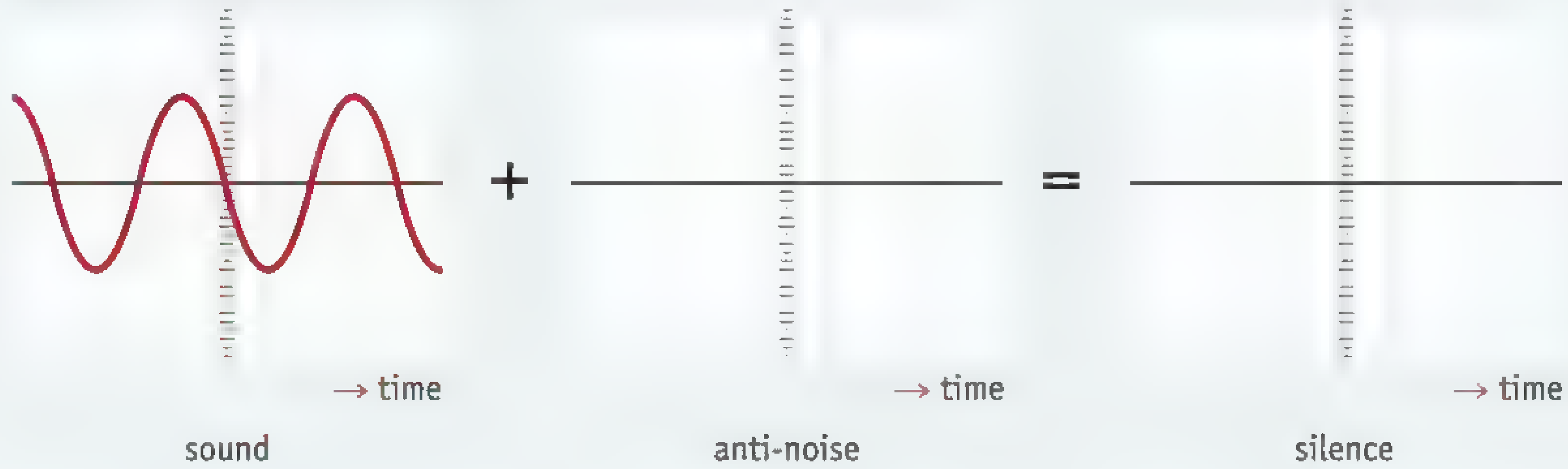
10 The graph in figure 8 shows a sound from the surroundings.

a Draw a graph in the middle of figure 8 showing the anti-noise that your noise-cancelling headphones produce.

b Draw a graph on the right of figure 8 showing the resulting sound that reaches your ear.

c Explain why it is important that the anti-noise is not too quiet and not too loud.

figure 8 Noise and anti-noise.



Experiments

EXPERIMENT 1 THE TUNING FORK

15 minutes

Introduction
Noise arises when objects vibrate, such as a tuning fork or a loudspeaker. The movement of the sound source also makes the surrounding air vibrate. That allows the sound to reach your ears.

Goal
In this experiment, you will be investigating the vibration of a tuning fork.

Requirements
- ☐ 440 Hz tuning fork
- ☐ glass beaker

Doing the experiment and writing it up
- Strike the tuning fork. Listen to the tone you hear.
- Strike the tuning fork again. Then place its foot against the table.
- Listen to the tone again.

1 What is the difference, compared to the first time?

....

....

- Strike the tuning fork. Touch one prong of the tuning fork with your fingernail.

2 What do you feel?

....

....

- Fill the glass beaker three-quarters full with water. Strike the tuning fork. Touch the water surface with one prong of the tuning fork. Take care not to touch the rim of the beaker!

3 What do you see?

....

....

- Strike the tuning fork and hold its foot against various parts of your head.

4 When does the tuning fork sound loudest?

....

....

EXPERIMENT 2 THE LOUDSPEAKER

15 minutes

Introduction
Loudspeakers contain a cone-shaped element that can move back and forth, which makes the surrounding air vibrate too.

Goal
In this experiment, you will be finding out how a loudspeaker makes the air vibrate.

Requirements
- ☐ loudspeaker
- ☐ 2 wires
- ☐ power supply box

Doing the experiment and writing it up
- Connect the loudspeaker up to a DC voltage of 4.5 V (figure 1). Watch the cone as you make the connection.

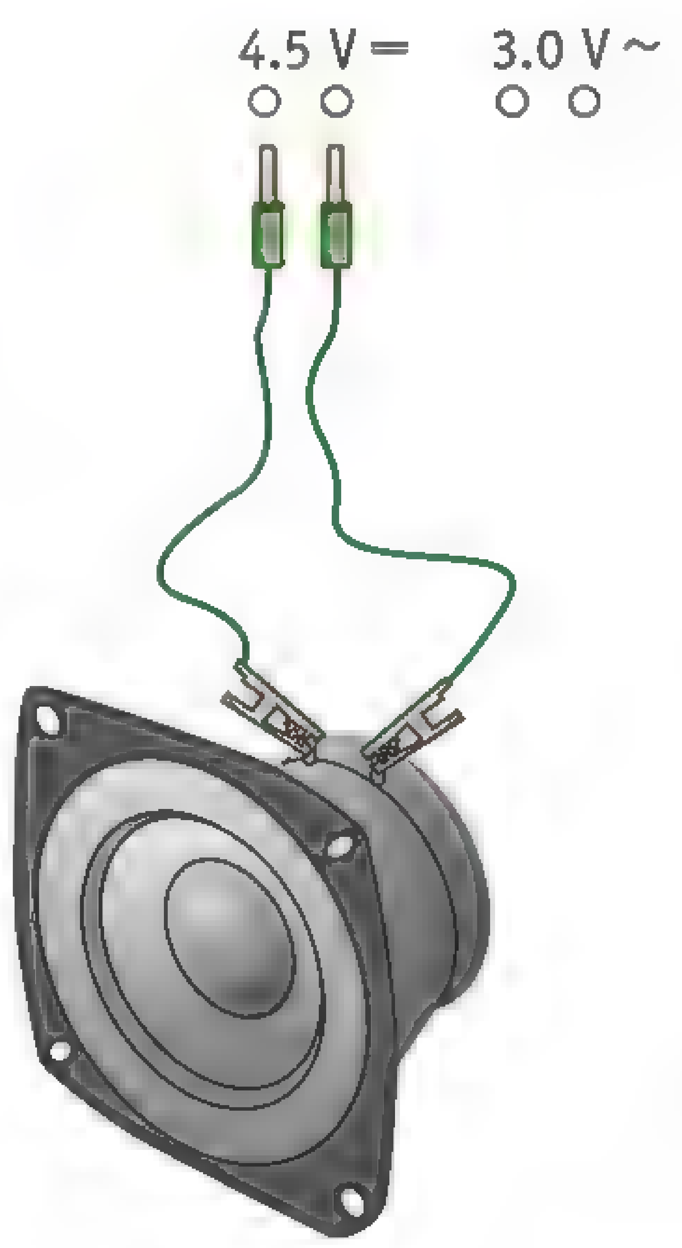


figure 1 The setup for Experiment 2.

1 Does the cone now move inwards or outwards?

....

....

- Swap the two connections on the power supply box over.

2 Does the cone now move inwards or outwards?

....

....

- Now connect the loudspeaker up to an AC voltage of 3 V.
- Take care! Don't use a voltage of more than 3.0 V!

3 What can you hear?

....

....

- Touch the cone gently.

4 What do you feel?

....

....

EXPERIMENT 3 YOUR VOICE AS A SOUND SOURCE

30 minutes

Introduction

When you talk or sing, you use the organs of speech. Your vocal cords produce vibrations that are then modified in your throat and mouth. This is how you generate voiced sounds such as "ah" and "mm". You can also use your tongue and lips to produce voiceless sounds such as a P and an S (in which the vocal cords are not vibrating).

Goal

In this experiment, you will investigate how you can use your voice to make all sorts of different noises.

Requirements

☐ a small mirror

Doing the experiment and writing it up

- Stretch your neck and lift your chin up. Place your fingers on your throat while you say 'mmm'.

1 Describe what you feel with your fingertips when you are saying 'mmm'.

....

....

- Hold the mirror just in front of your mouth, about 1 cm away (figure 2).

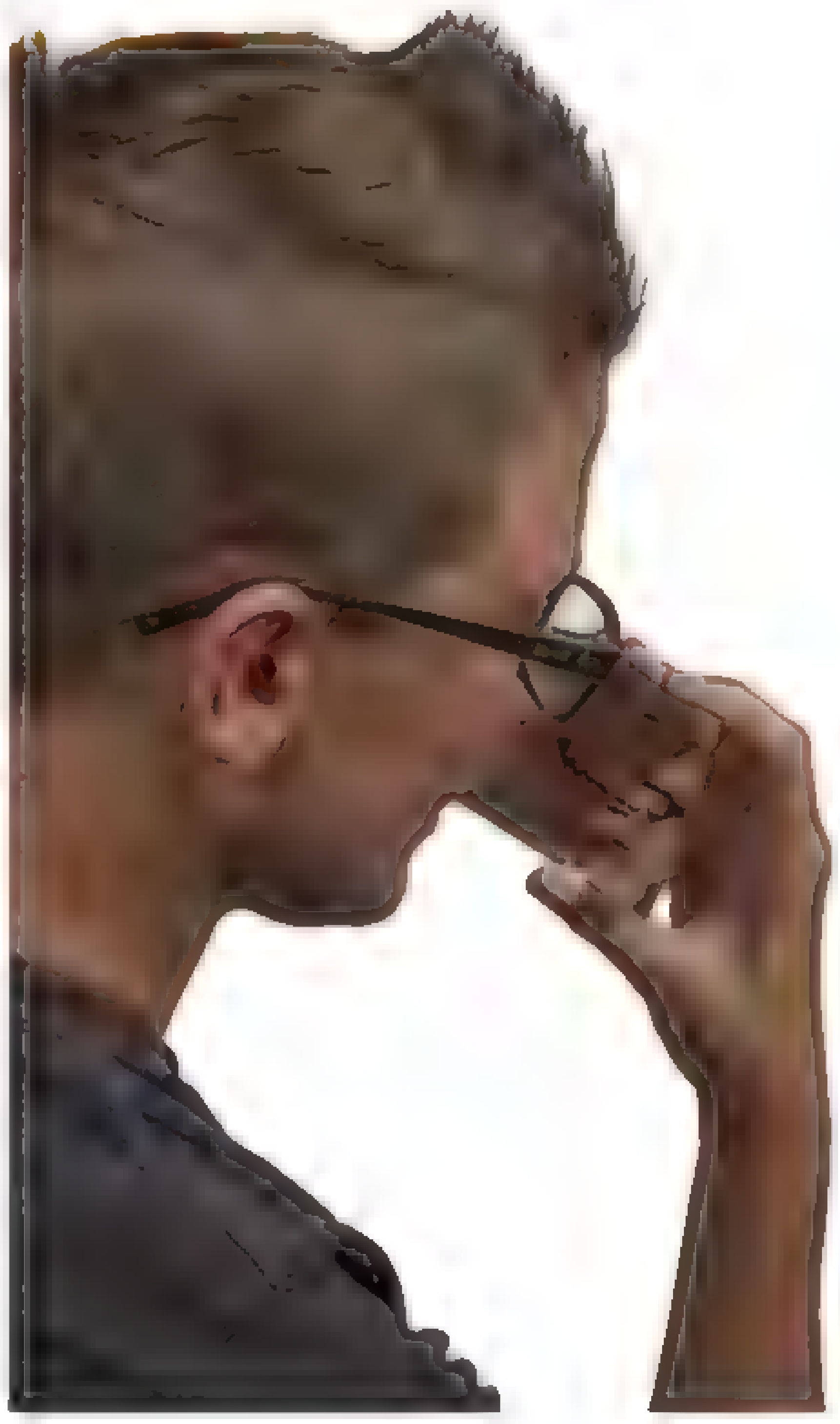


figure 2 Watch carefully how your mouth moves.

- Say the following a number of times, clearly and slowly: “The quick brown fox jumps over the lazy dog.”

2 Describe as accurately as possible the exact sequence for what you see.

....

....

....

- Put the mirror down. Now hold your hand just in front of your mouth while you repeat the same sentence.

3 Describe as accurately as possible the exact sequence for what you feel.

....

....

....

- Shine a light source into your mouth via the mirror, so that you can see right inside your mouth (figure 3).

figure 3 Have a good look at what your mouth is doing.

- Say 'ah' (hold the sound for a while) and look at your mouth in the mirror.

4 Describe as accurately as possible exactly what your mouth is doing.

....

....

....

- Say 'oh' (and hold the sound for a while).

5 Describe as accurately as possible exactly what your mouth is doing.

....

....

....

- Say 'ee'.

6 Describe as accurately as possible exactly what your mouth is doing.

....

....

....

- Put the mirror away.
- Watch your tongue carefully for the next task.
- Say 'rr' (a rolled R in the back of your throat, if you can).

7 What position was your tongue in when you said ‘rr’?

....

8 What did you feel moving in your mouth?

....

....

- Keep an eye on your tongue and lips as you say ‘ss’.

9 What position did you hold your tongue and lips in when you said ‘ss’?

....

10 Describe how the air was flowing out of your mouth.

....

....

- Say the letter ‘t’ a few times.

11 Explain as accurately as possible how you make this sound.

....

....

....

EXPERIMENT 4 TONES FROM STRINGS

30 minutes

Take care! If you tighten a string too far, it can break. This can be dangerous because the string can hit you with quite some force. You are therefore required to wear safety goggles for this experiment.

Introduction
A wide variety of musical instruments produce sound with vibrating strings. A guitar, for example, or a violin or a piano.

Goal
In this experiment, you will be investigating what factors affect the tone a string produces.

Requirements
- ☐ safety goggles
- ☐ 2 table clamps
- ☐ 2 wire tensioners
- ☐ thin metal wire
- ☐ thick metal wire
- ☐ tape measure

Doing the experiment and writing it up

- Put your safety goggles on!
- Place the table clamps 50 cm apart and clamp them onto the table.
- Stretch the thin wire between the clamps (figure 4).
- Tighten the thin wire a bit by turning one of the tensioning screws.
- Gently pull the middle of the wire with your index finger and then release it.

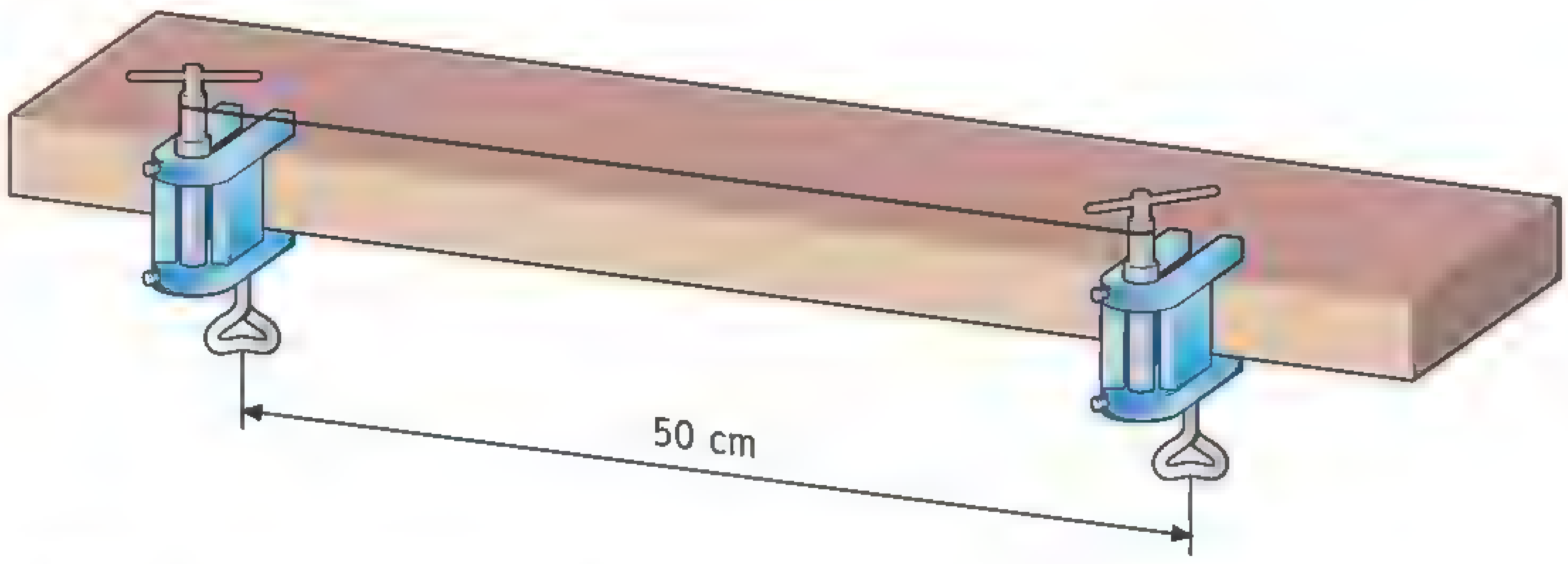


figure 4 The setup for Experiment 4.

1 How does the wire move?

....

....

- Pluck the wire again.
- Listen close to the wire.

2 Can you hear a sound? If so, what do you notice about the sound?

....

....

- Pluck the wire again to make it vibrate and then take hold of it again gently.

3 What do you feel?

....

4 Can you still hear sound when you take hold of the wire?

....

- Undo the thin wire from one clamp.
- Undo one of the table clamps too.
- Put the clamps close together, so that the distance is about 25 cm.
- Tighten the wire between the clamps again. Try to judge it so that the tension in the wire is the same as before.
- Pluck the wire again to make it vibrate and listen carefully.

5 Is the tone the same as the first time? If not, what is the difference?

....

....

- Undo the thin wire and put it aside.
- Move a clamp so that they are 50 cm apart again.
- Stretch the thick wire between the two clamps. Try to judge it so that the tension is the same as you used for the thin wire.
- Pluck the wire to make it vibrate and listen carefully.

6 Is the tone the same as the one the thin wire gave when it was 50 cm long? If not, what is the difference?

....

....

- Now place the clamps 25 cm apart and stretch the thick wire between them. Once again, try to judge the tension in the wire so that it is the same as before.

- Pluck the wire again to make it vibrate and listen carefully.

7 Is the tone the same as the thick wire of 50 cm produced? If not, what is the difference?

....

....

- Now tighten the wire a little more.
- Pluck it again to make it vibrate and listen carefully.

8 Has tightening the wire changed the tone? If so, how?

....

....

EXPERIMENT 5 THE VIBRATING RULER

10 minutes

Introduction
A musical scale consists of notes at different pitches. Each note has its own pitch, which depends on the frequency of the sound: the number of vibrations per second.

Goal
In this experiment, you make high and low tones using a ruler.

Requirements
☐ metal ruler

Doing the experiment and writing it up

- Press the ruler down firmly onto the table with your hand, leaving about 15 cm of the ruler sticking out over the edge of the table.
- Make the end vibrate by plucking it as shown in figure 5.
- Move the ruler so that 10 cm is sticking out over the edge of the table and make it vibrate again.
- Repeat this with 5 cm of the ruler sticking out.

1 What differences do you hear between the sounds?

....

....

....

2 When does the sound have the highest pitch?

....

....

3 When does the sound have the lowest pitch?

....

....

4 How can you tell that the vibration has died out after a few seconds?

....

....

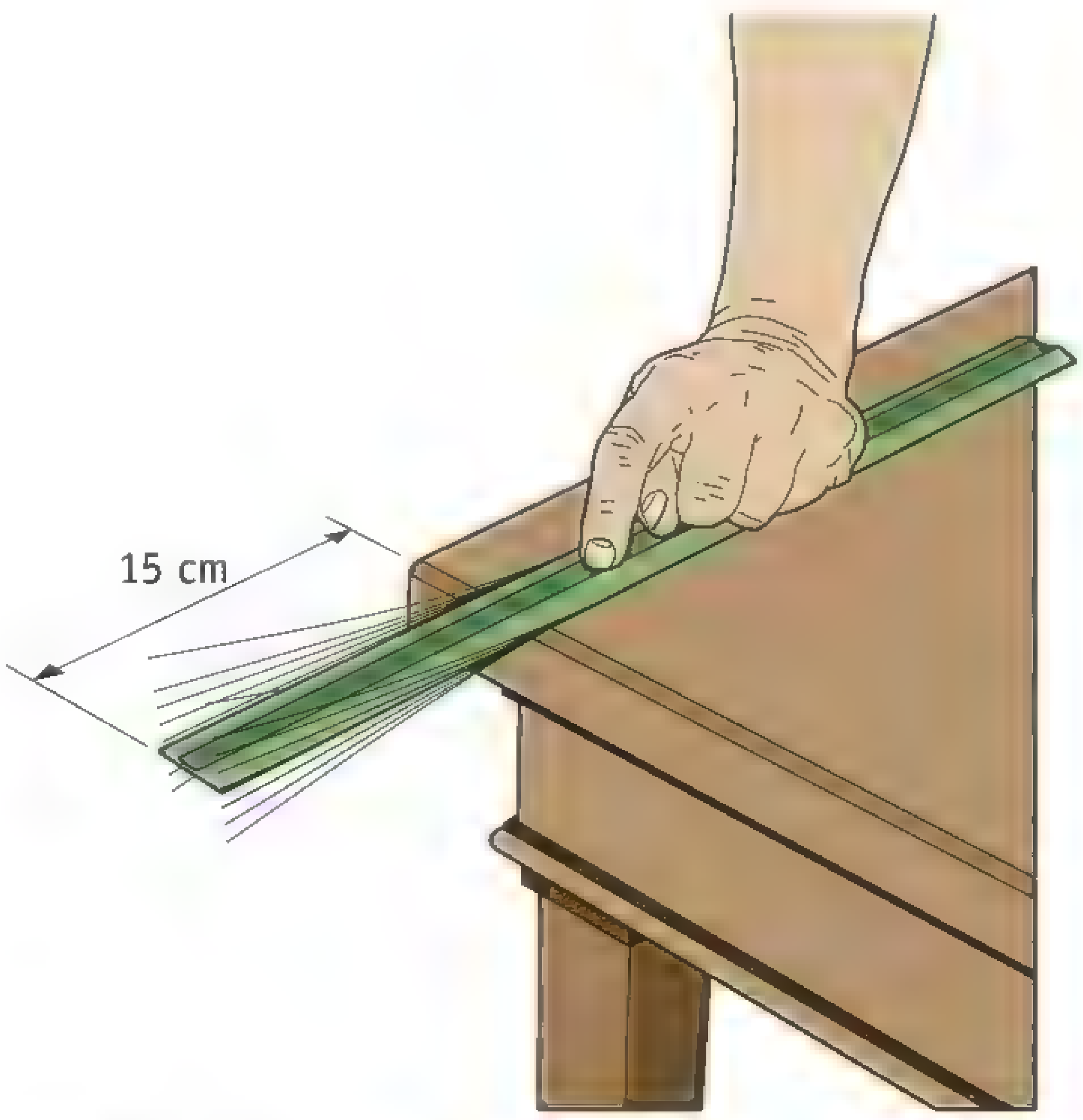


figure 5 This is how to make the ruler vibrate.

EXPERIMENT 6 THE FREQUENCY OF A VIBRATION

45 minutes

Introduction
If you make the end of a hacksaw blade vibrate, it vibrates with a fixed period. You can alter the vibration period by attaching a mass to the end of the hacksaw blade.

Goal
You are going to investigate how the frequency of a vibrating hacksaw blade depends on the mass at the end of the blade.

Requirements
- ☐ hacksaw blade
- ☐ masses of 50 g
- ☐ stopwatch
- ☐ stands
- ☐ graph paper

Doing the experiment and writing it up
Measuring
- Attach the hacksaw blade to the stand, as shown in figure 6.
- Attach a mass of 50 g to the end of the blade.
- Make the blade vibrate. Use the stopwatch to measure the time required for ten vibrations. Do this a total of three times.

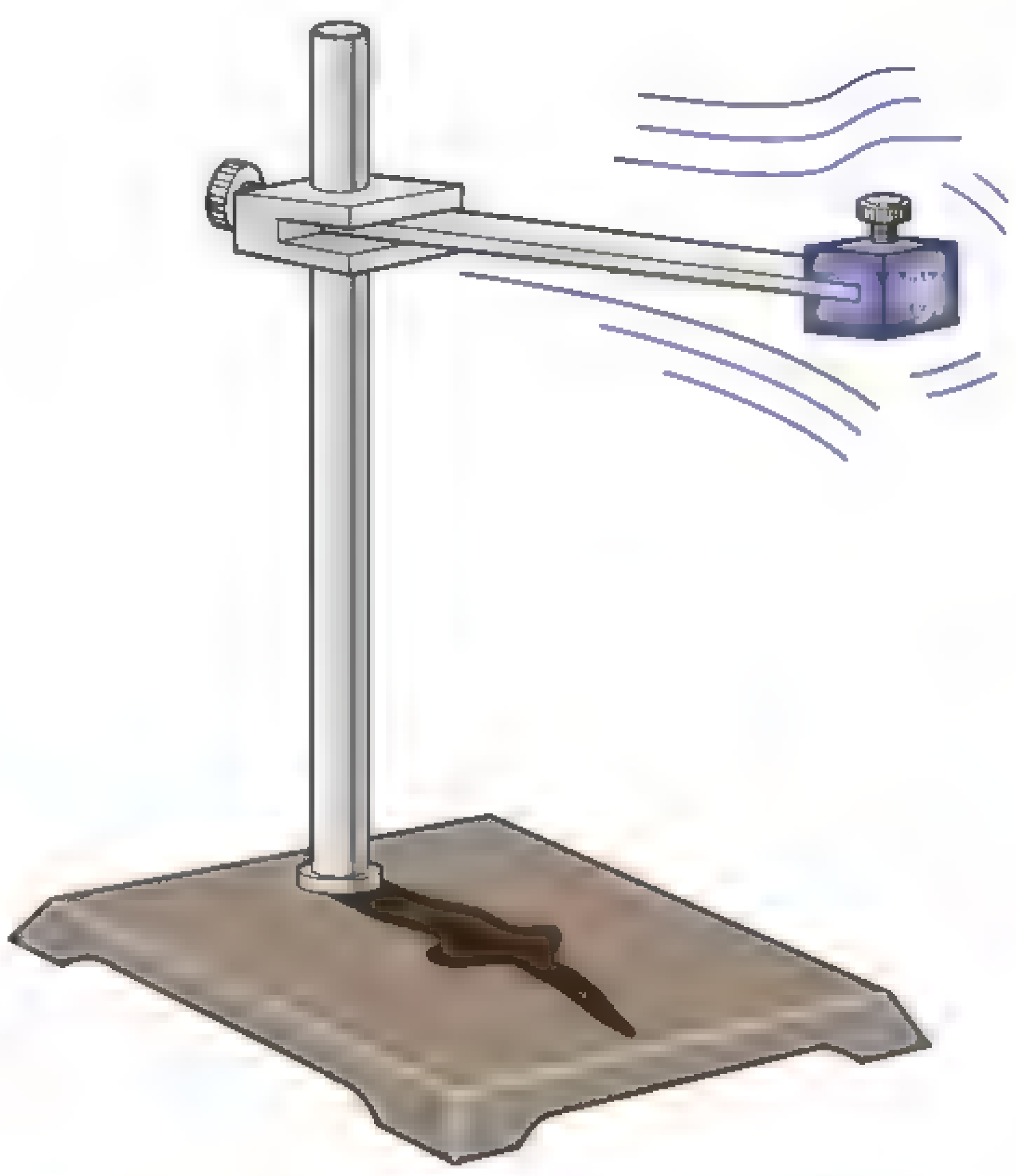


figure 6 The setup for Experiment 6.

1 Write down your timings in table 1.

2 Calculate the average of the three measurements. Round the result off to one decimal place. Write down this value at the correct place in the table.

table 1 The measurements for Experiment 6.

	measurement 1	measurement 2	measurement 3	average	T (s)	f (Hz)
saw blade with 50 g						
saw blade with 100 g						
saw blade with 150 g						

3 Calculate the time needed for a single vibration. This is known as the period T of the vibration. Write this result down in the table.

4 Calculate how many vibrations the hacksaw blade makes in a single second. Round off to one decimal place. This is called the frequency f of the vibration. Write down the result in the table.

- Attach masses of 100 g and then 150 g to the end of the hacksaw blade. Determine the frequency of the blade's vibration for each mass.

5 Write down all the measurements in the table.

Writing up

6 Draw a graph of your experiment on graph paper, plotting the frequency against the mass.

7 What conclusion can you draw from the graph?

....

....

....

....

....

....

8 What would happen to the tone made by a tuning fork if you were to screw a weight to each prong?

....

....

....

....

EXPERIMENT 7 AN INVESTIGATION INTO THE RISKS OF LOUD MUSIC

45 minutes

Introduction

Suppose that you read in the newspaper that hearing damage among young people due to loud music is an “underestimated and growing problem”. According to a researcher, sound levels at music festivals and discos are “much too loud” and are having “an enormous impact”. Other culprits are phones, which are generally turned up much too loud. According to the researcher, more than half of young adults have hearing loss of 10 dB or more. You wonder whether it really is as bad as all that and you decide to investigate this yourself.

Goal

In this experiment, you are going to be investigating the noise levels of music to see how much of a risk the listeners are running. Think up a good research question of your own for this research.

Requirements

You can carry out this investigation using a smartphone or tablet that you have downloaded a suitable app onto. You can find an appropriate app by typing in “hearing apps” or “decibel meter apps” (including the quotation marks).

Doing the experiment and writing it up

- Think about how you can give the most reliable answer to the question. How are you going to find out what volume is ‘normal’ for your listeners? How are you going to measure the sound level (and have you chosen the right app)? How are you going to define the relationship between your measurement results and the risks being run by the listeners?

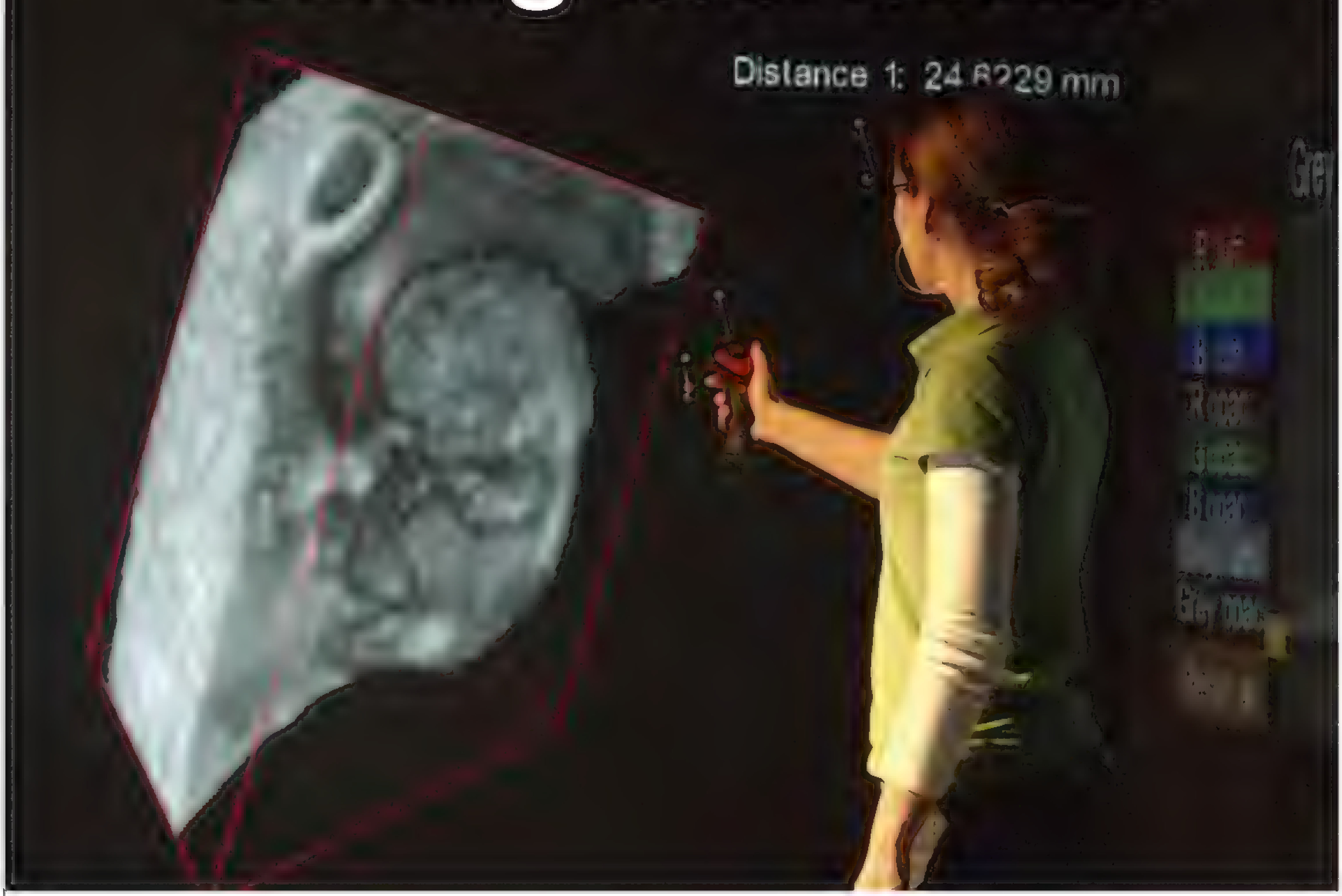
1 Make a work plan for this study.

- The work plans will be discussed with the rest of the class in the next lesson. If necessary, you can make improvements to your own work plan after that.
- Then carry out the experiment.

2 Note down all the measurements, calculations and results in your exercise book.

- Your teacher will tell you whether or not you have to write up a report on this experiment.

Seeing with sound



"When you put the 3D glasses on, you can see the embryo hanging in space before your eyes, hugely magnified and completely three-dimensional. You get the feeling that you could simply reach out and touch it. That feeling gets even stronger if you use the pointer to rotate the baby so that you can look at it from another angle. If you don't watch out, you forget that it's only a picture. Very ingeniously produced, but a picture all the same."

A new form of ultrasonography

Doctors at the Erasmus Medical Centre are enthusiastic about a new ultrasonography technique in which the results of the scan are shown in a 3D spatial representation. The virtual reality software that produces the 3D images has been developed by the Bioinformatics department of the hospital in Rotterdam. Doctors can use the new system to follow the development of an embryo right from the first weeks of the pregnancy. This will let them monitor high-risk pregnancies particularly closely.

Sonar: eyes under the water

All sorts of methods have been developed over the course of time to allow 'vision' using sound. The 3D ultrasonography at the Erasmus Medical Centre is the latest step in a long sequence of developments. The basic idea is actually very simple. Sound is reflected at the boundaries between different materials. You can find out where that boundary is located by emitting sound waves and waiting until the reflection – the echo – comes back to you.

The first application of this basic idea was in sonar (an abbreviated form of *sound navigation and ranging*). That is a technique that uses sound to let you detect objects under the water surface. Sound is reflected very strongly at the boundary between ice and water, for example. Sonar can therefore be used to detect icebergs under the water (figure 1). That is extremely useful because 90% of an iceberg is underwater and so it can present an invisible hazard.

Sonar became a great success. The technique was used not only for detecting icebergs but also for navigating in shallow waters and

Sonar can be used to detect icebergs under the water.

figure 2 To make the first ultrasound scans, the patient had to sit in a bath.

for locating shoals of fish. During the Second World War, sonar was an important tool for detecting enemy submarines. Using sonar was one of the reasons that the Allies won the submarine battle against Nazi Germany.

An explosive experiment

Other ideas for using sound to create images of objects soon appeared. In 1921, a group of researchers in the United States carried out an experiment to test one such idea. They exploded a large dynamite charge to send powerful sound waves into the ground. Just like the inventors of sonar, they were interested in the reflections that might be generated.

The researchers knew that the sound waves would bounce back at the boundary layer between two different rock strata. But they did not know if the reflections would be strong enough for them to be detected on the surface. It turned out that they were strong enough, and so reflection seismology was born. This technique is now used throughout the world for tracking down subterranean gas and oil reserves.

Echoes from inside the body

The success of sonar and reflection seismology gave physicians an idea: maybe they could use sound to produce images of the inside of the body. After all, there are all sorts of boundary layers within the body as well, for example between soft tissue and hard bone.

It became clear very quickly that they were not going to get far with normal sound. The things that a doctor wants to see are far smaller than an iceberg or a rock stratum and so you cannot use normal, audible sound for visualizing them. That needs ultrasound, which has a much higher frequency. and therefore a much shorter wavelength: the sound waves are much closer together and capable of being used to produce images of smaller objects.

The first experiments with ultrasound were carried out between 1940 and 1950 (figure 2). The researchers attempted to use it to localize brain tumours. It was not a great success. It did produce an image of the brain, but the image remained very unclear. What was clear, though, was that the researchers were onto something useful. The technique was perfected in the years that followed until good, clear images could be produced with it.

figure 1 Sonar can therefore be used to detect icebergs under the water.

Having a scan

Ultrasonography – having a scan or a 'foetal echo' – uses a sonde that contains a series of piezoelectric crystals. The electronics make these crystals emit a short pulse of ultrasound. The sound propagates through the body, with reflections occurring at the boundary layers between different tissues. The crystals pick the echoes up again and convert them into an electrical signal.

A computer uses the signals from the crystals to build up an image of the body. To produce that image, an average speed of sound of 1540 m/s inside the body is assumed. The speed of sound is not exactly the same in all tissues, but the average speed nevertheless gives a usable result. One key advantage of ultrasonography is that you can use it to investigate soft tissues that cannot be seen on an X-ray.

Before the examination starts, the sonographer list smears a special gel on the skin (figure 3). The gel is needed to ensure good contact between the sonde and the body. If there is air between the sonde and the skin, a very strong reflection comes back from the boundary between the air and the skin, because they are two totally different 'materials'. The sound waves are then reflected before they can even get into the body, and that naturally does not produce good pictures.

Echoes in 3D

By putting several cross-sections together, a computer can build up a three-dimensional image. The result is normally viewed on an ordinary screen or printed out on normal paper. The image itself only has two dimensions, although it is representing a three-dimensional situation. That type of image cannot generate the illusion of 'real' depth.

figure 3 Ultrasound examination in a pregnant woman.

SONAR IMAGES OF THE TITANIC

The first patent for sonar was applied for in 1912, one month after the famous passenger ship *Titanic* had collided with an iceberg and sunk. The disaster cost the lives of more than fifteen hundred people. In 2012, a century later, the wreck of the *Titanic* was accurately mapped out using advanced sonar cameras. The images are a convincing demonstration of just how far technology has now come.

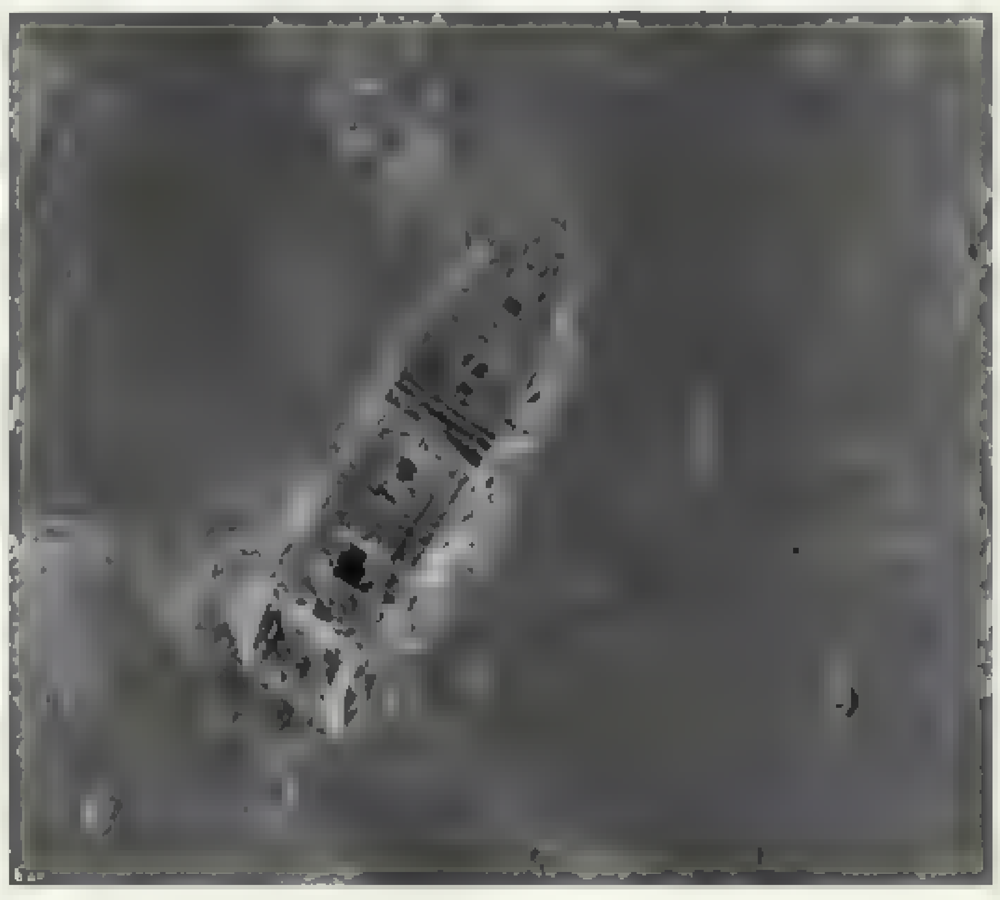


figure 4 The wreck of the *Titanic*.

EXERCISES

1 To determine the position of the reflection, the computer uses an average value of 1540 m/s for the speed of sound. People who are obese (very overweight) have thick layers of fat. The average speed of sound in fat is lower, between 1462 and 1473 m/s. Explain whether a fat layer will appear too thick, too thin or at the right thickness in ultrasonography.

2 The first ultrasonography devices were very large, much bigger than the sondes that are used now. To have an echo, the patient had to sit in a bath.
Think what the reason might have been for making the sonogram underwater.

3 You cannot see details on an echo that are smaller than the wavelength of the sound used. The wavelength is the distance between successive peaks of the sound waves (the areas in which the pressure is higher than average).

- **a** Sound at 1540 Hz has a wavelength of about 1 m in the human body.
  Use the data from this article to show that this statement is correct.
- **b** The sounds used for ultrasonography have frequencies of 1 to 10 MHz.
  Calculate the wavelength of this sound.

Course material overview

8.1 MAKING AND HEARING SOUNDS

REMEMBER

- Sound is produced by vibrations in a sound source.
- Sound needs a medium in which the vibrations can be transmitted. That can be a gas, a liquid or a solid.
- The speed of sound in air at 20 °C is 343 m/s.
- You can calculate the distance sound travels using the formula $s = v \cdot t$.
- When a sound reaches your ear, the eardrum vibrates. Those vibrations are converted into signals that go to your brain and you then perceive the sound.

CONCEPTS

medium
Substance that vibrations can propagate in from the sound source to your ears.

sound source
Object that produces sound because it (or something inside it) vibrates.

speed of sound
Speed at which sound waves propagate in a medium.

8.2 PITCH AND FREQUENCY

REMEMBER

- A string makes a lower tone if it is thicker, longer or less taut.
- The frequency of a tone is the number of vibrations a second. The higher the frequency, the higher the pitch of the tone you hear.
- You can use an oscilloscope to visualize a vibration and read off the vibration period.
- You can use the formula $f = \frac{1}{T}$ to work out the frequency for a given vibration period. If you use the vibration period T in seconds, you get the frequency f in hertz (Hz).
- Humans can hear tones from 20 to 20,000 Hz. This is called the frequency range.

CONCEPTS

frequency
Number of vibrations per second.

frequency range
Frequencies that a human or animal can hear.

microphone
Device that converts pressure differences in the air into electrical signals.

oscilloscope
Instrument that displays vibrations on a screen.

tuning
Adjusting a musical instrument so that it produces tones of the desired pitch.

time base
Timescale used on the oscilloscope.

vibration period
Time required for a single complete vibration.

8.3 SOUND INTENSITY

REMEMBER

- A louder sound means a greater amplitude.
- You measure sound intensity in decibels (dB) using a decibel meter (sound level meter). A tone of 0 dB and a frequency of 1000 Hz is one that you are just unable to hear.
- The greater the distance to a sound source, the lower the sound intensity.
- Your threshold of hearing and the pain threshold depend on the frequency: your ears are less sensitive to low tones and very high ones.
- For measuring noise nuisance, an A filter is used. Like your hearing, this filter is less sensitive to low tones and very high tones. The unit of sound intensity for this measurement is the dB (A).
- If the number of sound sources doubles, the sound level increases by 3 dB.

CONCEPTS

A filter
Name for a filter that adapts a decibel meter to match the sensitivity characteristics of the human ear. Just like the human ear, the decibel meter is then less sensitive to low tones and very high tones.

amplitude
Maximum displacement away from the centre position. The sound intensity increases as the amplitude becomes greater.

decibel meter, sound level meter
Device that lets you measure the sound intensity.

limit of detection
Sound intensity at which you are just beginning to be able to detect the sound.

pain threshold
Sound intensity at which your ears start to hurt.

sound intensity
Sound intensity says how loud a sound is. The unit of sound intensity is the decibel (dB).

8.4 COMBATING NOISE NUISANCE

REMEMBER

- Whether or not a noise is harmful for your hearing depends on the intensity and how long you are exposed to it for.
- Noise that is not harmful can nevertheless be a nuisance, for example causing a lack of sleep and concentration problems.
- It is important not to expose your ears to too much loud noise as this helps avoid permanent hearing damage. A beep or ringing in your ears is a sign of (hopefully only temporary) hearing damage.
- Measures to tackle noise nuisance can be taken at the sound source, between the source and receiver, or at the receiver.
- Noise barriers (embankments) and noise screens reduce the nuisance caused by traffic noise. Noise barriers damp out the sound by absorbing it; noise screens reflect it away.

CONCEPTS

noise barrier / embankment
Thick layer of earth alongside a motorway, for instance, to absorb the noise.

noise screen
Screen that can reflect sound away.

sound insulation
Layer of insulating material such as glass wool to absorb the sound.

Go to the *Flash cards* and the *Diagnostic test*.

Skills

DOING RESEARCH

Physics and chemistry are subjects that teach you how to do research. You work with practical equipment, make measurements, draw graphs and do calculations. This part of the book is about the skills that you need in order to do this.

1 Carrying out research

Physics and chemistry are subjects that teach you how to carry out research yourself. When you are doing research, you set about it step by step.

Step 1: **Think of a study question**
The question you are investigating is usually already stated in the book – in which case this step won't take long. Sometimes the book lets you think up a study question of your own, though. Don't be content with it too quickly. And you must have some idea of how you could answer your question.

Step 2: **Make a working plan**
In your working plan, you should write down:
- what materials and equipment you will need;
- what experimental setup you are going to construct (make a drawing);
- what variables you are going to measure;
- which formulae you are going to use (if applicable).

Figure 1 gives an example of a working plan.

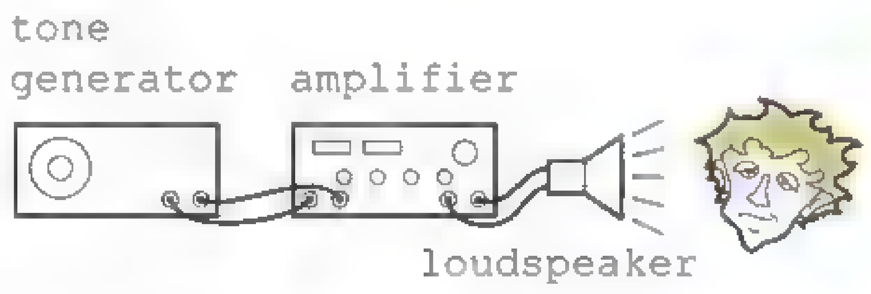
```
Working plan by: Eileen and Jamila

Study question: What is the highest tone
we are able to hear?

1   Materials and equipment

  * Tone generator
  * Amplifier
  * High-frequency loudspeaker

2   Setup
```

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3   Measurements

Jamila uses the tone generator to produce
increasingly high-pitched sounds. Eileen
says "stop" when she can no longer hear
the sound. Jamila then looks at the tone
generator to see how high the frequency was.
We do this a number of times to see if we
consistently get the same value. Then we
do the test again, but this time with Jamila
listening and Eileen turning the knobs
on the tone generator.
```

figure 1 A working plan may look something like this.

Step 3: **Doing the experiment and writing it up**
You are now going to make the measurements and do the calculations with them. See also Skills 5 to 11.

Step 4: **Drawing conclusions**
If everything has gone as intended, you are now able to draw your conclusions. Try to give an answer to your study question. You should also think about what you could have done better in your research.

Step 5: **Writing a report**
Finally, you make a report of your research. See the skills section on 'Writing a report'.

2 Working with variables and units

Experiments and study assignments often need you to make measurements. You use a measuring instrument to find a numerical value for a property, such as a length or a temperature.

Variables

A variable is a property that you can measure with a measuring instrument. Examples of variables are length, mass and temperature. You can measure these variables with a ruler (for the length – see figure 2), scales (for the mass) or a thermometer (for the temperature).

figure 2 The variable 'height' is measured in the unit 'metres'.

Units

Before you can measure a variable, a scale of sizes has to be agreed. This scaling is known as a unit. You measure lengths in metres, mass in kilograms and your body temperature in degrees Celsius.

There is an internationally recognised SI unit for every variable, such as the metre for length, the second for time and the ampere for the strength of current. Other units are also used in daily life. People do that because they find these units handier, or simply because it is what they're used to.

Writing down measurement results

- Before making the measurements, determine what units your measuring instrument gives the results in. That is often immediately clear, but sometimes you do have to look carefully first.
- Always write a measurement result down straight after taking the measurement.
- If you are you only making a single measurement, write the measurement result down in this form:
  [variable] = [number] [unit].
  For example, mass = 237 grams or m = 237 g.
- If you are making a series of measurements, you should then record your measurement results in a table. Above each column of numbers, you should write:
  - what variable you have measured;
  - which units you have used (in brackets).

Table 1 gives a summary of the variables and units that you will come across in this book. The third and fourth columns give the SI units. Other widely used units are listed in the last two columns.

Sometimes you have to convert a value from one set of units to another (for instance from km/h to m/s). See Skills 4 for this.

table 1 Variables and units.

variable	abbreviation	SI unit	abbreviation	other units	abbreviation
air pressure, gas pressure	p	pascal	Pa	bar	-
current	I	ampere	A	-	-
density	ρ	kilograms per cubic metre	kg/m^3	grams per cubic centimetre	g/cm^3
frequence	f	hertz	Hz	-	-
length, distance	l	metre	m	-	-
mass	m	kilogram	kg	-	-
power	P	watt	W	-	-
speed	v	metres per second	m/s	kilometres per hour	km/h
temperature	T	kelvin	K	degrees Celsius	°C
time	t	second	s	minute, hour	min, h
voltage	U	volt	V	-	-
volume	V	cubic metre	m^3	litre	L

3 Working with prefixes

A unit may sometimes be awkwardly large or indeed awkwardly small. A method has therefore been developed for making units that are the 'right size'.

The prefixes in table 2 can in principle be used for any unit. You can for example make derived units that are 10, 100 or 1000 times larger or smaller than the original unit. This lets you adjust the size of the unit to suit the situation: kilograms for the mass of your body, but milligrams for the amounts of active ingredient in a tablet.

In practice, some combinations are widely used and others very rarely or never. The decibel (dB) is a popular unit, for example, but you will never come across a decivolt (dV) or deciwatt (dW).

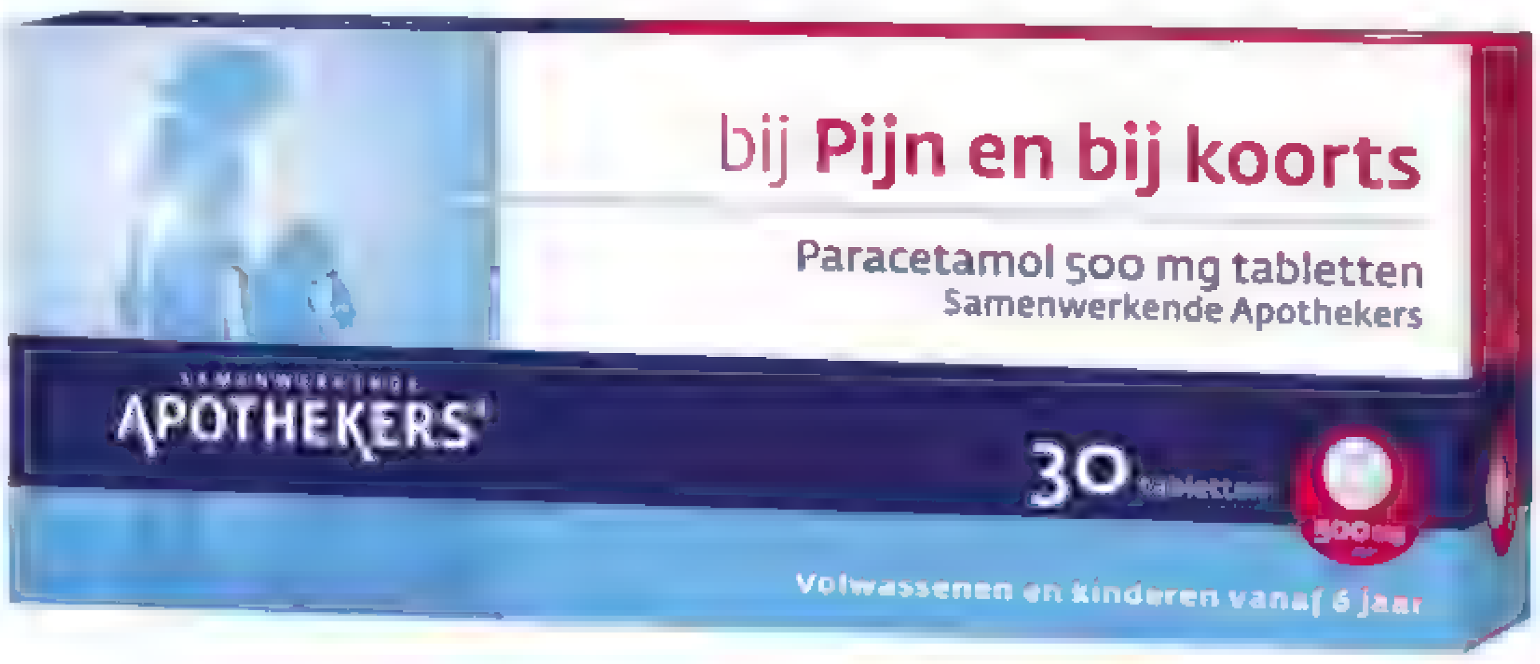


figure 3 A painkiller with 500 mg of the active ingredient per tablet.

Choosing a unit

- When doing your experiments, you should look to see what units are stated on the measuring instrument. It is generally simplest to use those units.
- Choose a smaller unit if you would otherwise end up using very small numbers (< 0.1). Write down the result of a volume measurement as 25 mL, for example, rather than 0.025 L.
- Use a larger unit if you would otherwise end up with very large numbers (> 1000). Write down the result of a calculation as 340 km, for example, rather than 340,000 m.

Sometimes you have to convert a value from one set of units to another (for instance from mA to A). See Skills 4 for this.

table 2 Prefixes and their meanings.

prefix	abbreviation	meaning	example
kilo	k	1000	1 kg = 1000 g
hecto	h	100	1 hPa = 100 Pa
deca	da	10	1 dam = 10 m
deci	d	1/10 or 0.1	1 dL = 0.1 L
centi	c	1/100 or 0.01	1 cm = 0.01 m
milli	m	1/1000 or 0.001	1 mA = 0.001 A

4 Converting units

You often have to convert from one set of units to another. You might for instance do this if you have calculated the speed in m/s but someone asks you what that is in km/h.

When you need to convert units, you do it as follows:

Step 1: **Write down an equation with one unit on the left and the other on the right.**

Step 2: **Determine which number you need to multiply or divide.**

Step 3: **Do the appropriate multiplication or division and write down the result.**

EXAMPLE EXERCISE 1

A measuring cylinder contains 0.125 L water. How many millilitres is that?

Step 1: Remember (or look up) the fact that 1L is the same as 1000 mL – see figure 4.
Step 2: You are going from litres to millilitres, so you have to multiply by 1000.
Step 3: Work it out: The volume of the water is $0.125 \times 1000 = 125$ mL

EXAMPLE EXERCISE 2

An ammeter shows 82 mA. How many amps is that?

Step 1: Remember (or look up) the fact that 1 A is the same as 1000 mA.
Step 2: You are going from mA to A, so you have to divide by 1000.
Step 3: Work it out: The current = $\frac{82}{1000} = 0.082$ A

EXAMPLE EXERCISE 3

A cyclist's speed is 5.2 m/s. What is that in km/h?

Step 1: Remember (or look up) the fact that 10 m/s is the same as 36 km/h.
Step 2: You are going from m/s to km/h, so you are multiplying by 3.6.
Step 3: Work it out: The speed = $5.2 \times 3.6 = 19$ km/h

figure 4 As you can see from this measuring jug, 1 L is the same as 1000 mL.

5 Reading measuring instruments

When you make a measurement, you read off a measured value – a number – from a measuring instrument. This is easier for some measuring instruments than for others.

A digital measuring instrument such as a stopwatch or a digital clinical thermometer is electronic. The measured value is shown in numeric form on a screen. These types of meters make it very easy for you: all you have to do is write down the numbers.

An analogue measuring instrument such as a measuring cylinder or an analogue voltmeter uses a graduated scale. You read off a measuring cylinder by looking to see which mark the liquid level is at. For an analogue voltmeter, you look to see which mark the needle is pointing at.

For measuring instruments such as these, you cannot read off the measurement value immediately.
First, you have to know how much each mark represents. You can work that out as follows:

Step 1: **Go from the zero to the first numbered mark.**
In the measuring cylinder in figure 5, this is the line with a 20 next to it.

Step 2: **Go to the line half way between the zero and the first number.**
Work out what value belongs with this mark. For the measuring cylinder, that would be 10.

Step 3: **Now determine the value of each individual mark on the graduated scale.**
Count from 0 up to the first number to check that you've got it right.
For the measuring cylinder, it will work out correctly if you count in steps of 2 mL.

So each marker on the measuring cylinder represents 2 mL.
Confirm for yourself that this measuring cylinder contains 62 mL of water.

You can use the same method for other measuring instruments with graduated scales.

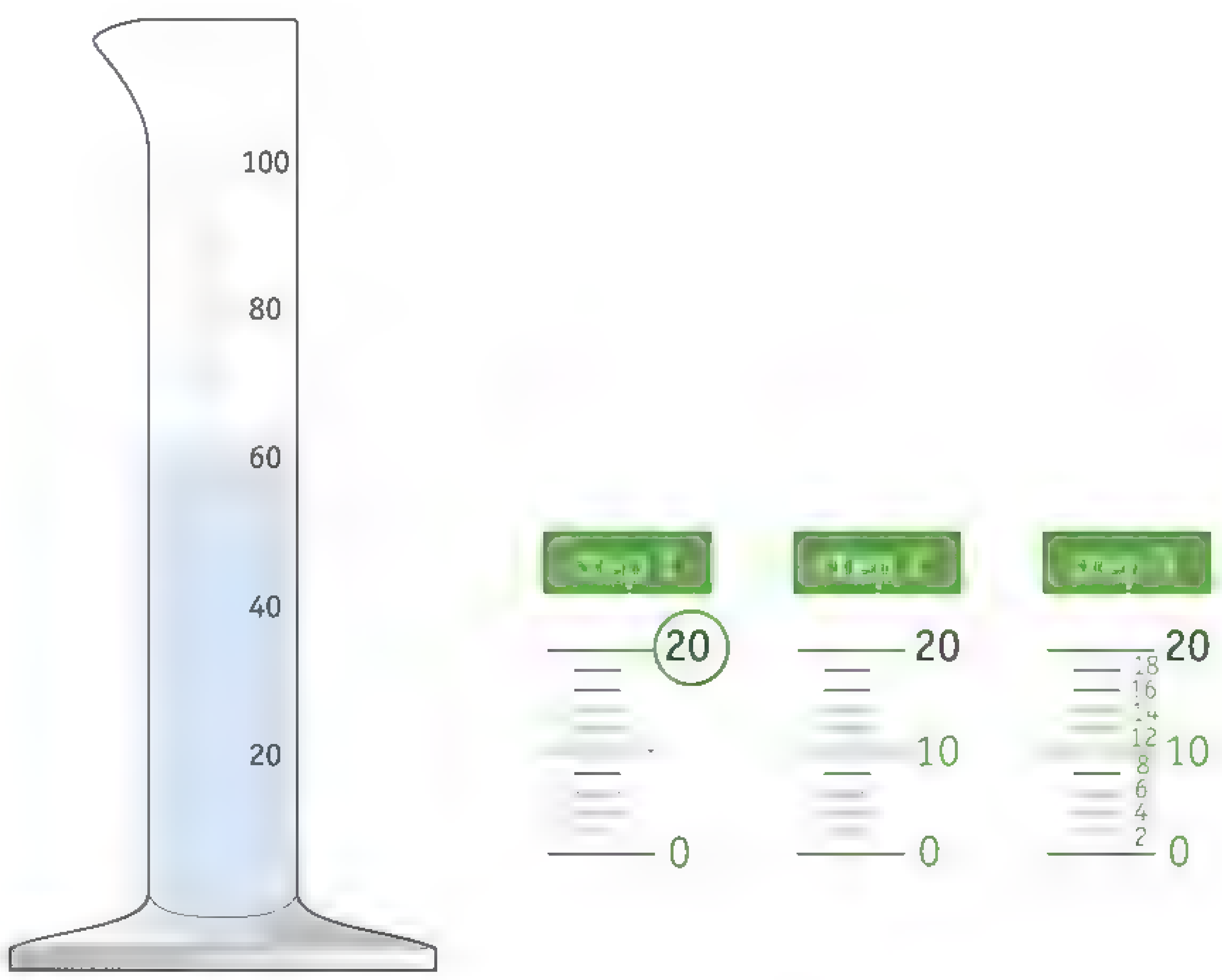


figure 5 How to read a measuring cylinder.

6 Working with a Bunsen burner

For physics and chemistry, you will sometimes use a Bunsen burner. The instructions below tell you how to use it.

Safety

- Stick to the safety rules that you have discussed with your teacher.

Before starting

- Check that the gas control knob and air control ring of the burner are closed (figure 6). If not, close them.

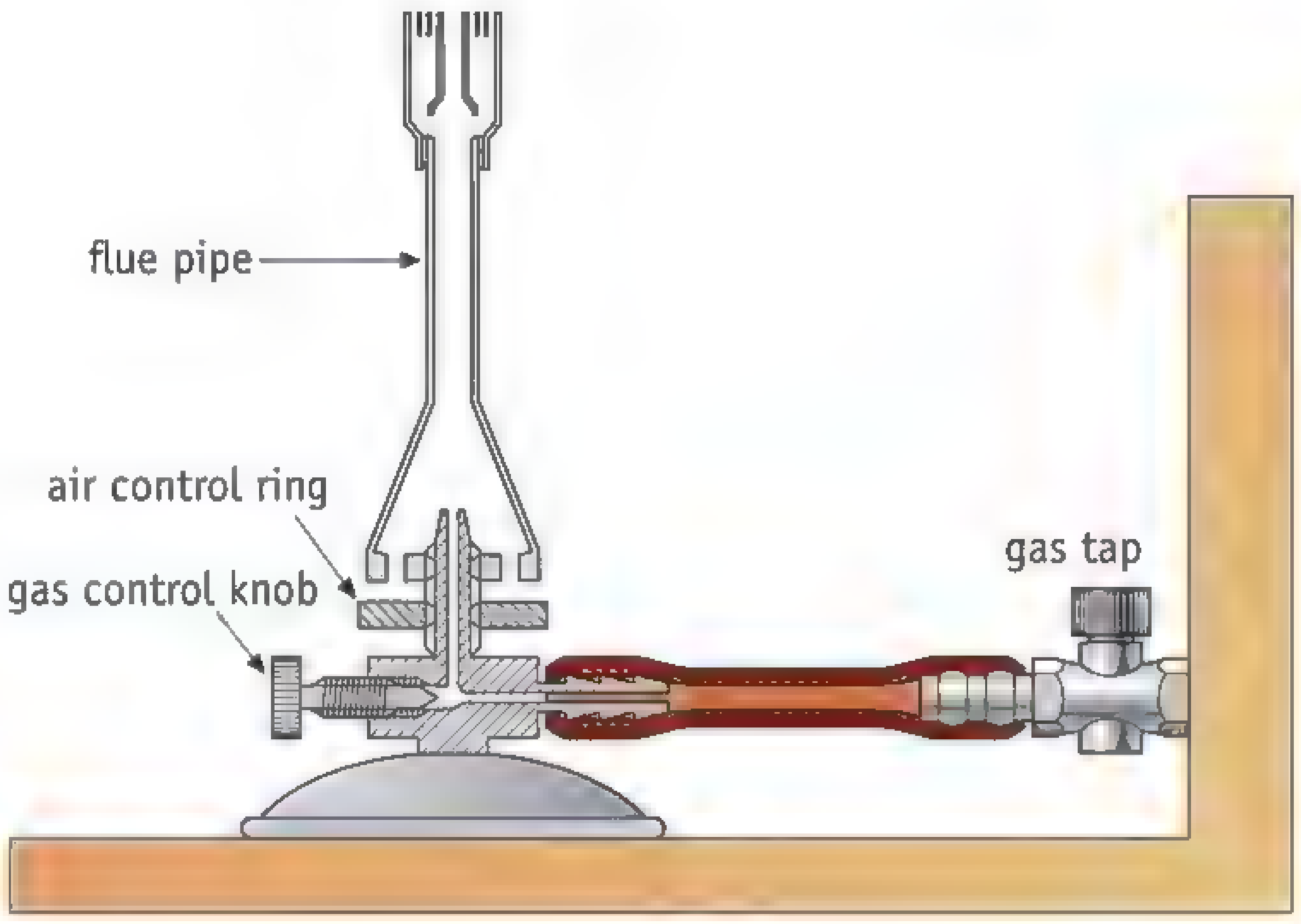


figure 6 The parts of a Bunsen burner.

Lighting

- Open the gas tap on your bench.
- Hold a lit match above the burner.
- Open the gas control knob.
- The burner will now burn with a clearly visible, yellow flame.

Heating

- Open the air control ring.
- The burner now burns with a poorly visible, blue flame. This blue flame is much hotter than the yellow flame. You generally use a quietly hissing, blue flame to heat things (never a yellow flame).

Interrupting an experiment

- Do not leave the Bunsen burner unattended when the flame is blue.
- Always close the air control ring first.
- The burner then burns with a clearly visible, yellow flame.

Turning it off

- Close the air control ring.
- Close the gas tap on your bench.
- Close the gas control knob.

7 Working with a voltmeter

Experiments with electricity often use a voltmeter. You must connect this kind of meter up correctly.

Connecting

- To measure the voltage across a bulb, you connect the voltmeter up in parallel with the bulb. See figure 7.
- Connect the positive terminal of the battery or power supply up to the positive connection on the voltmeter. The needle will then move in the right direction. If it nevertheless goes wrong, you should connect the two wires to the meter the other way around.

Measurement ranges

- Many voltmeters have various different measurement ranges. The meter in figure 7, for instance, has three measurement ranges: 0–3 volts, 0–15 volts and 0–30 volts. If you use the 0–3 volt measurement range, you can measure voltages up to a maximum of 3 volts.
- Do a test measurement first using the largest measurement range. This helps make sure that the meter will not get damaged. You can then see clearly whether or not you can use a smaller measurement range.
- You should then make the measurements using the smallest possible measurement range. The needle will then move further and you can read what it is showing more accurately.

Reading

- Always look at the meter as directly from the front as possible and do your best to read the value off accurately.

figure 7 How to connect up a voltmeter.

8 Working with an ammeter

Experiments with electricity often use an ammeter. You must connect this kind of meter up correctly (figure 8).

Connecting

- To measure the current through a bulb, you connect the ammeter in series with the bulb. The current flowing through the bulb then also has to flow through the meter.
- Connect the positive terminal of the battery or power supply up to the positive connection on the ammeter. The needle will then move in the right direction. If it nevertheless goes wrong, you should connect the two wires to the meter the other way around.

Measurement ranges

- The ammeter will usually let you choose from a number of different measurement ranges. The meter in figure 8 has three: 0-50 mA, 0-500 mA and 0-5 A. If you use the 0 to 500 mA measurement range, you can measure currents of a maximum of 500 mA.
- Do a test measurement first using the largest measurement range. This helps make sure that the meter will not get damaged. You can then see clearly whether or not you can use a smaller measurement range.
- Then do the measurement with a smaller measurement range if possible. If you can see that the current is about 30 to 40 mA, for example, you could switch down to the 0-50 mA range. The needle will then move a long way and you can read accurately what it is showing.

Reading

- Always look at the meter as directly from the front as possible and do your best to read the value off accurately.

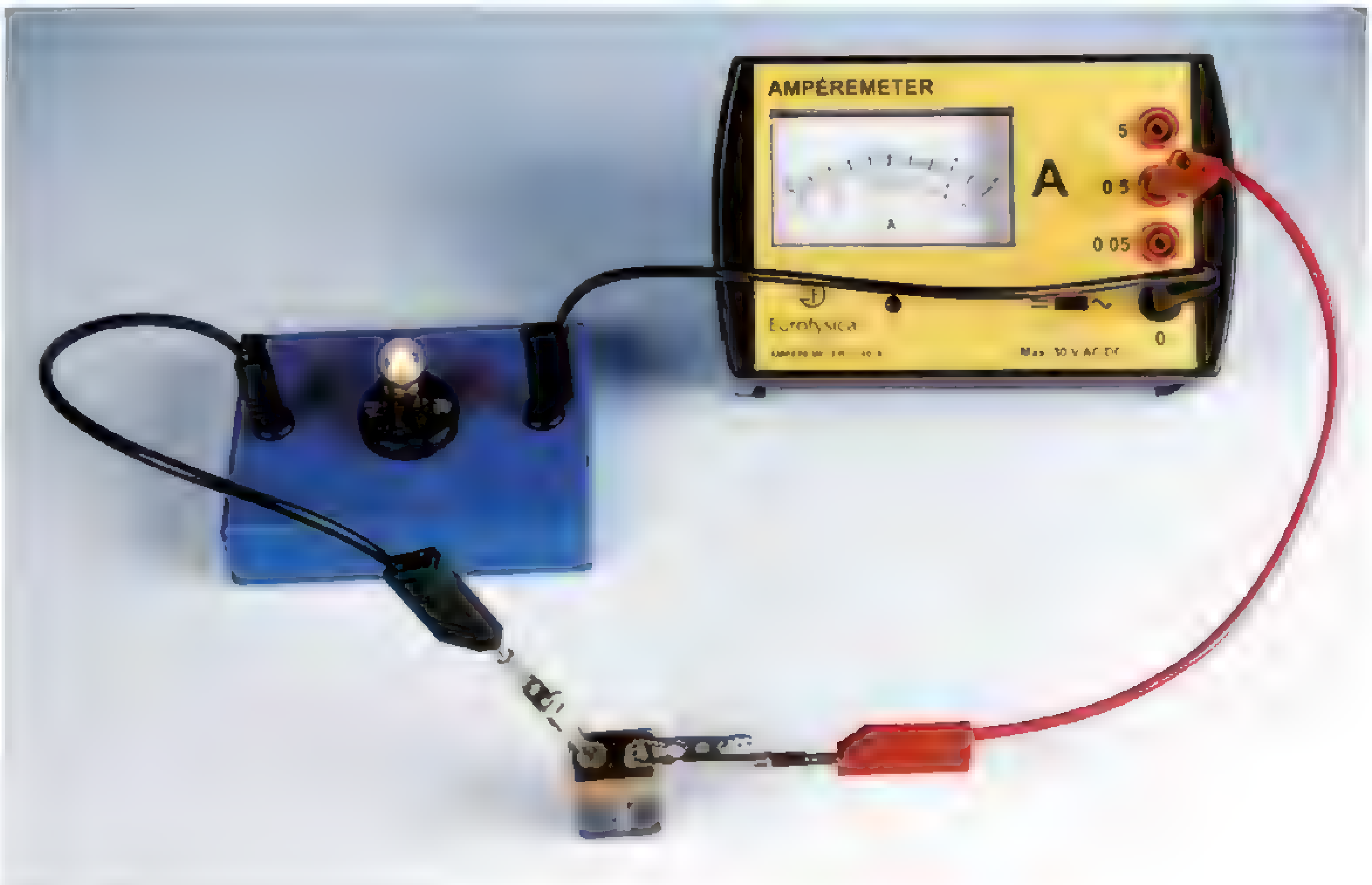


figure 8 How to connect up an ammeter.

9 Working with a multimeter

In experiments with electricity, you can use a multimeter instead of a voltmeter or an ammeter. There is a knob on the meter that makes it easy to choose the variable being measured and the desired measurement range (figure 9).

Measuring a voltage

- Turn the knob to the area marked "DCV" or "V=" and select the largest measurement range.
- Connect the multimeter up like a voltmeter: in parallel with the bulb.
- Make a test measurement. Repeat this if necessary using a smaller measurement range.
- Finally make the 'real' measurement using the smallest possible measurement range.

Measuring a current

- Turn the knob to the area marked "DCA or "A=" and select the largest measurement range.
- Connect the multimeter up like an ammeter, in series with the bulb.
- Make a test measurement. Repeat this if necessary using a smaller measurement range.
- Finally make the 'real' measurement using the smallest possible measurement range.

figure 9 A multimeter.

10 Building circuits

For some experiments, you use a circuit diagram to help put a circuit together. The best way to build a circuit is to do it step by step. Figure 10 shows you how.

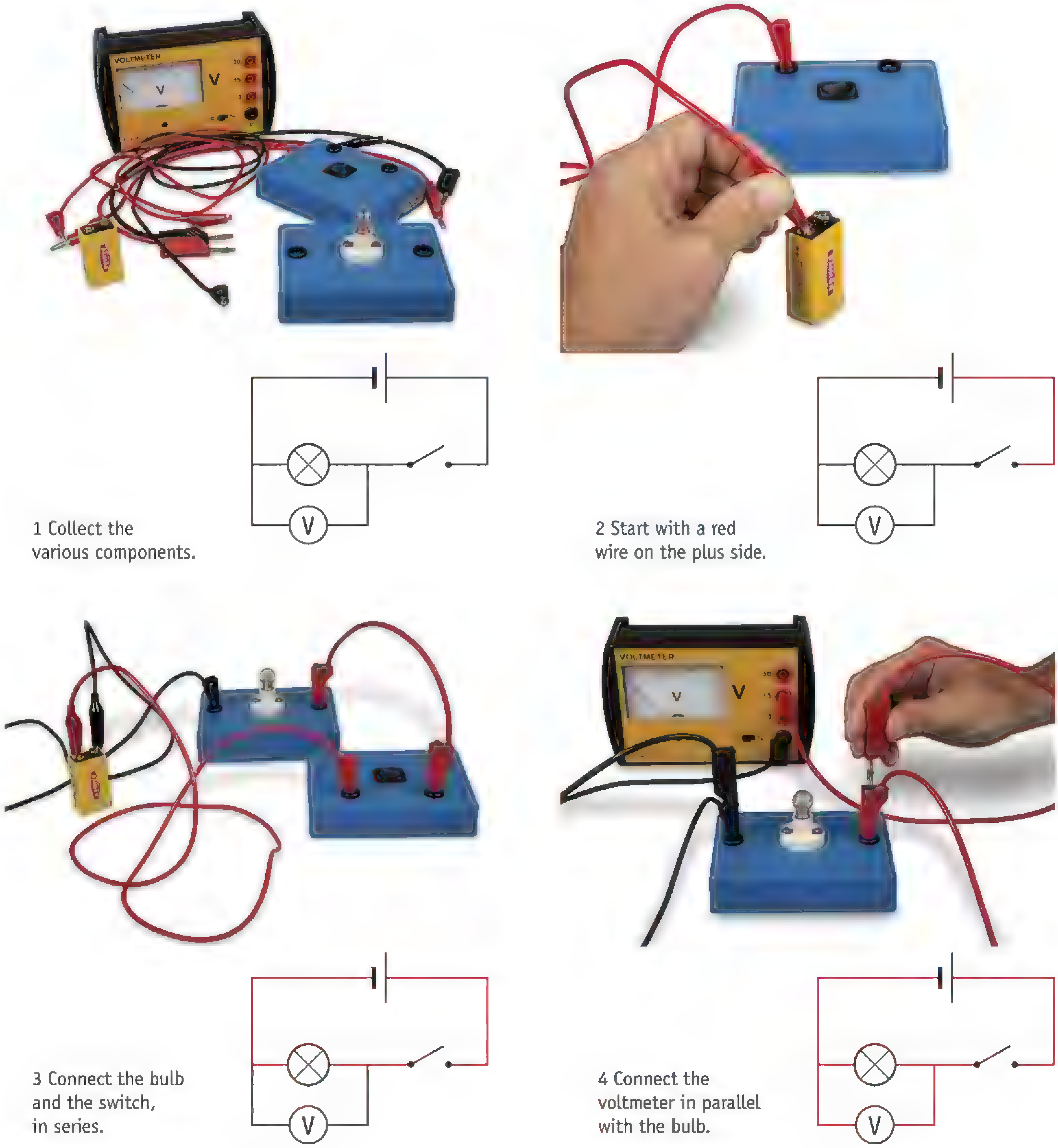


figure 10 Building a circuit.

11 Working with an oscilloscope

An oscilloscope lets you determine the frequency of a tone. To do that, you first have to connect a microphone up to the input of the oscilloscope. The screen then shows a picture of the sound vibration.

The time base

The oscilloscope screen is subdivided into squares. Time is presented along the horizontal axis. If a single square is 2 milliseconds wide, we say that the time base is set to 2 milliseconds per division (2 ms/div). You can set the time base on the oscilloscope yourself.

Setting the time base

- Sometimes there will be too many vibrations on the screen at once. You should then set the time base to a smaller value.
- Sometimes all you can see is a small part of a single vibration. You should then set the time base to a larger value.
- The time base is set correctly if you can see just a few vibrations on the screen. You are then easily able to read off from the screen how much time is needed for a single vibration (figure 11).

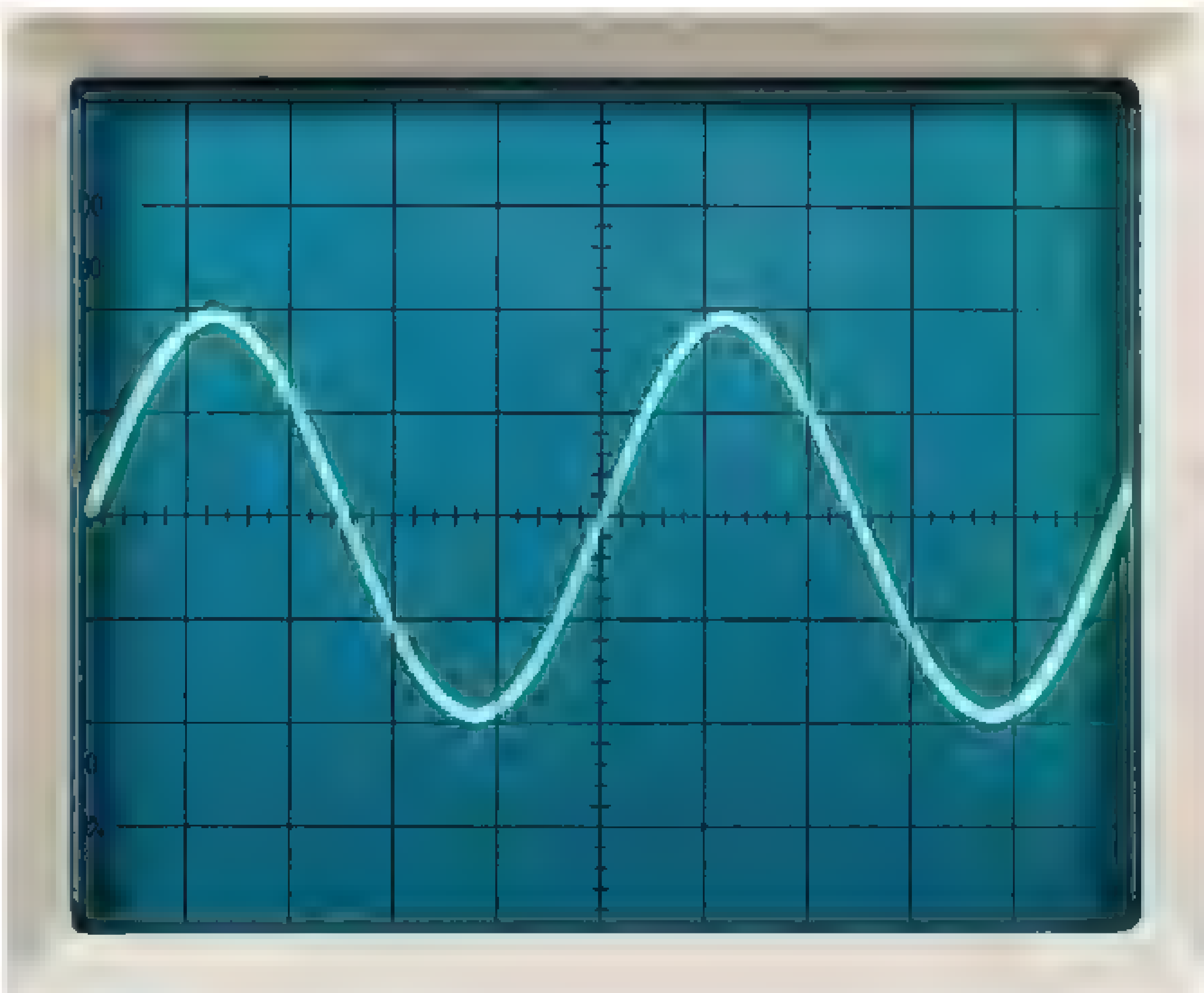


figure 11 An oscilloscope picture of a vibration.

EXAMPLE EXERCISE

The time basis for the oscilloscope in figure 11 is set to 2 ms/div (2 milliseconds per division).
Calculate the frequency of the vibration shown.

You can see that one complete vibration takes up five squares.
$T = 5 \times 2 \text{ ms} = 10 \text{ ms} = 0.01 \text{ s}$

$$f = \frac{1}{T} = \frac{1}{0.01} = 100 \text{ Hz}$$

On analogue oscilloscopes, you use a knob to set the time base (figure 12). On digital oscilloscopes, you can also set the time base yourself or you can press the auto-set button to let the oscilloscope find the most suitable time base (figure 13).

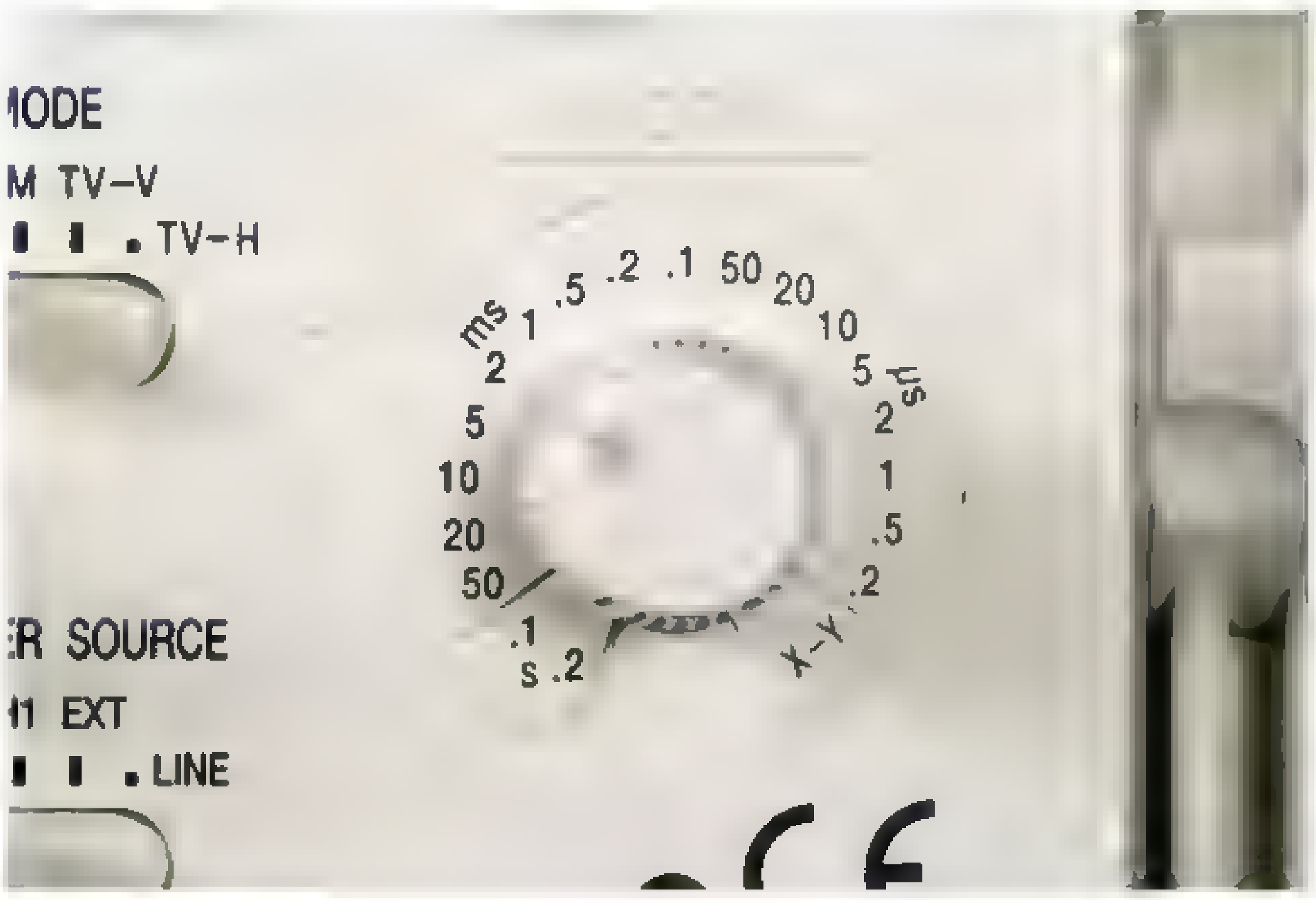


figure 12 The time base of an oscilloscope.

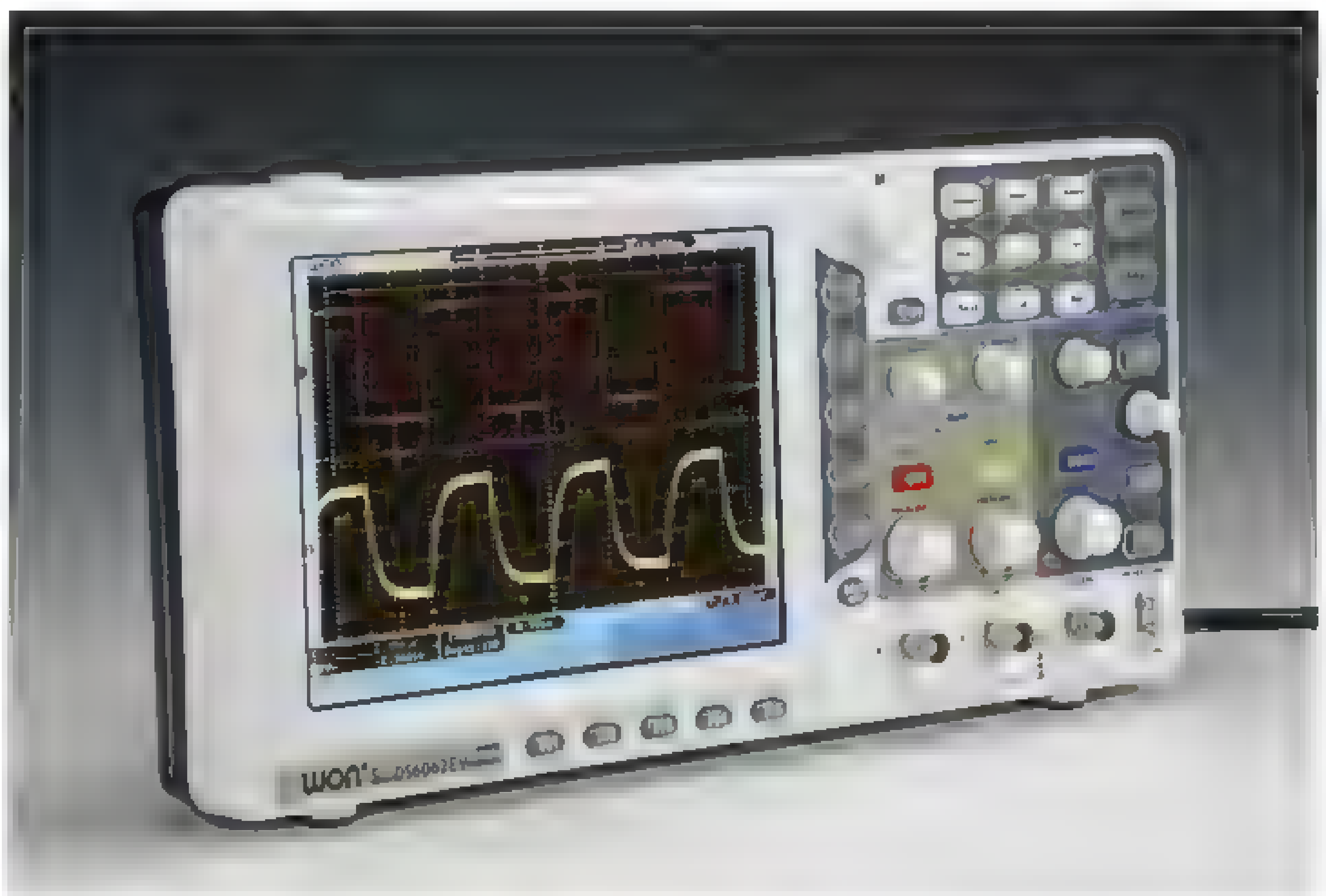


figure 13 A digital oscilloscope.

12 Working with formulae

For physics and chemistry, you will sometimes need to do calculations. You have to be able to show clearly how you got your answer.

You should therefore show the working for your calculations as follows:

Step 1: **Write down all the data you are using.**

Step 2: **Write down what you are being asked to find.**

Step 3: **Write down the formula in an appropriate form.**

You write down the formula for the power P as:

- $P = U \cdot I$ if you have to calculate the power P.
- $U = \frac{P}{I}$ to calculate the voltage U.
- $I = \frac{P}{U}$ to calculate the current I.

Step 4: **Fill in the data.**

Step 5: **Write down the answer, as a number followed by its units.**

Round the answer off if your answer would otherwise contain too many digits. A good rule of thumb is that your answer should have the same number of digits as (or at most one more digit than) the data item with the fewest digits.

EXAMPLE EXERCISE

A metal cylinder has a mass of 196 g and a volume of 22 cm^3.
Calculate the density of the material that the cylinder is made of.
What substance might it be?

given $m = 196$ g
$V = 22$ cm^3

required $\rho = ?$

working $\rho = \frac{m}{V} = \frac{196}{22} = 8.9$ g/cm^3

The cylinder could very well be made of copper: see table 1 in Section 4 of Chapter 2.

13 Working with tables and graphs

Many study questions are about the relationship between two variables. Take the following study question, for example:
What is the relationship between the temperature of water in a glass beaker and the time for which the water is heated?

This question is about the relationship between time and temperature. To answer the question, you carry out a series of measurements. You heat the water with a Bunsen burner. Once a minute, you read the water temperature from a thermometer. You then write down the measurement results in a table (see figure 14a). After completing the experiment, you show the measurement results in a graph. You make a graph as follows (see figures 14b, c and d):

Step 1: **Draw a set of axes.**

Step 2: **Label each axis with a variable and the corresponding units, for example 'time (min)' and 'temperature (°C)'.**

Step 3: **Draw an appropriate scale along each of the axes.**

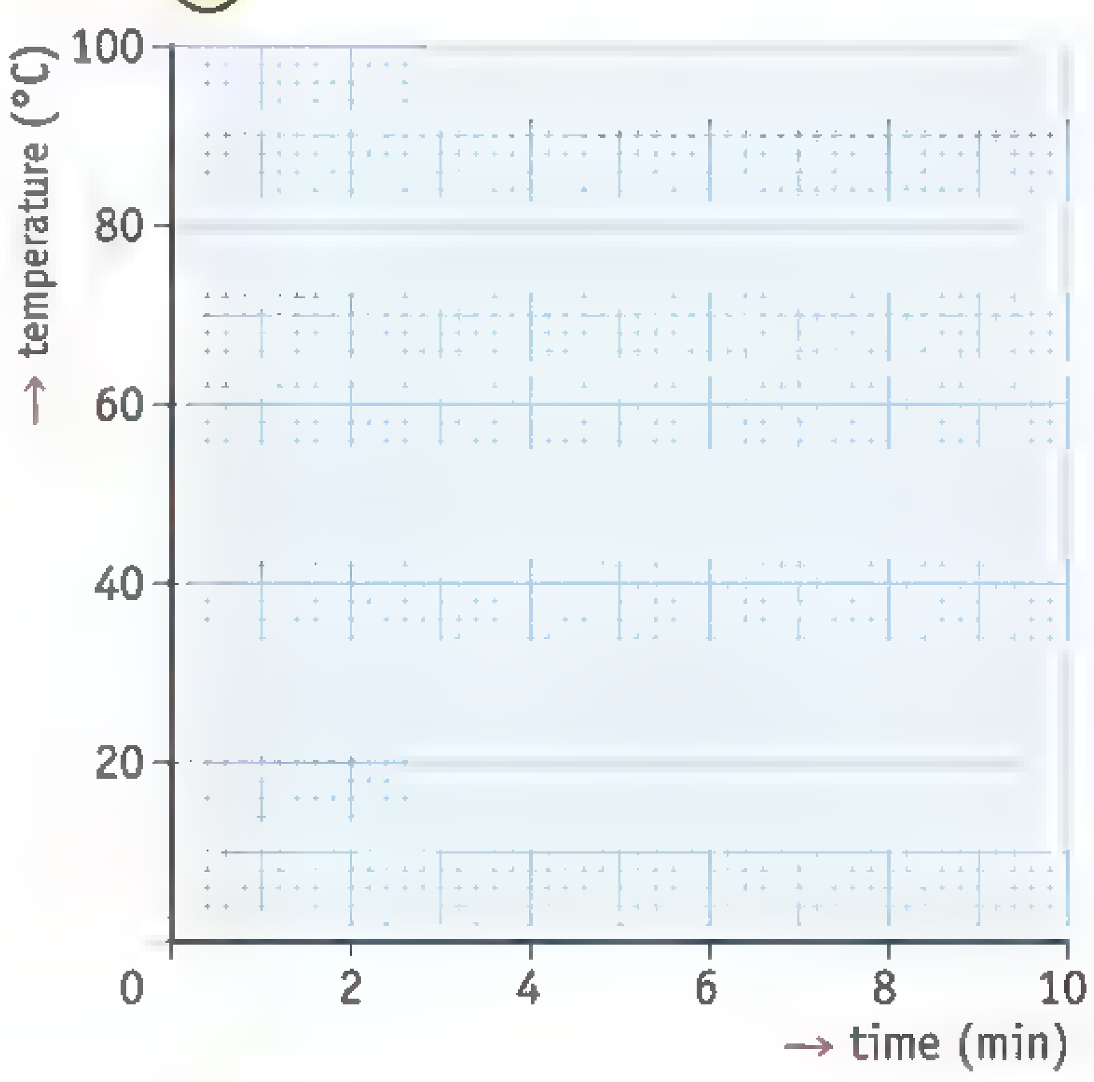
Step 4: **Plot in the measurements as points.**

Step 5: **Draw a straight line or a smooth curve that fits the points as well as possible. You should not simply join the dots.** In other words, it doesn't matter if the straight line or curve does not go precisely through all the measurement points.

a

time (min)	temperature (°C)
0	20
2	48
4	72
6	95
8	100
10	100

b



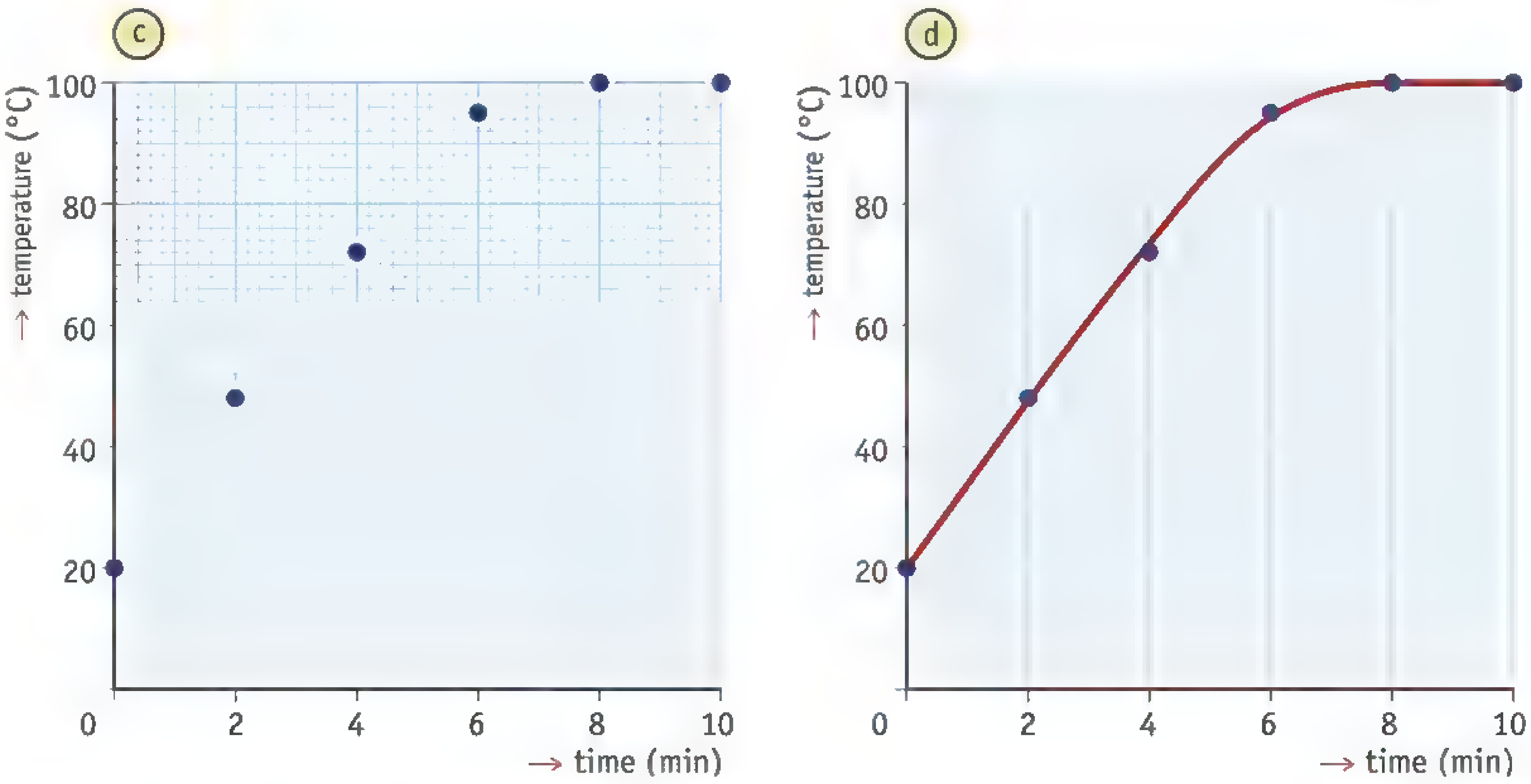


figure 14 From a table to a graph.

14 Writing a report

Research has to be written up. In the report, you explain what happened during the experiment. Somebody who was not actually there must be able to understand exactly what happened. Sometimes you also have to write a report of a practical experiment or a home assignment.

Lay your report out like this:

Title page
This is where you can give the title of the report, the names of the pupils in the group doing the experiment, the class, the name of your teacher and the date and year.

Section 1 Study question
This section is where you explain what question you wanted your study to answer.

Section 2 Working plan
This contains:
- a list of the things you used;
- a drawing of the experimental setup you made;
- a brief description of what you did.

Section 3 Experimental results
This is where you can state what you observed or measured. This can be in textual form or as tables, graphs, photographs and so forth.

Section 4 Conclusions
The answer to the study question can be stated here.

A report should look good. It is not only about the information that your report contains: you must also present that content clearly and neatly.

Glossary

A

A filter A-filter
Filter waarmee je een decibelmeter aanpast aan de gevoeligheid van het menselijk oor. Net als menselijke oren wordt de decibelmeter dan minder gevoelig voor lage en heel hoge tonen.

absorbe absorberen
Opnemen; licht dat niet wordt teruggekaatst, wordt opgenomen.

acceleration versnelde beweging
Beweging waarvan de snelheid toeneemt.

air pressure luchtdruk
Atmosferische druk op aarde.

amplitude amplitude
Maximale uitwijking van een trilling ten opzichte van het midden. Als de amplitude groter wordt, neemt de geluidssterkte toe.

angle of incidence hoek van inval
Hoek tussen de invallende lichtstraal en de normaal.

angle of reflection hoek van terugkaatsing
Hoek tussen de teruggekaatste lichtstraal en de normaal.

artificial light source kunstmatige lichtbron
Voorwerp dat zelf licht geeft en door de mens is gemaakt, bijvoorbeeld: kaarsen, lampen en tl-buizen.

atmosphere atmosfeer
Mengsel van gassen dat de buitenste laag van een planeet vormt.

atmospheric pressure atmosferische druk
Druk die ontstaat door het gewicht van de gassen in de atmosfeer van de planeet.

average speed gemiddelde snelheid
Afstand die is afgelegd gedeeld door de benodigde tijd.

axial rotation aswenteling
Draaiende beweging van de aarde rond de aardas, waardoor dag en nacht ontstaan.

B

barometer barometer
Instrument waarmee je de atmosferische druk meet.

baseline basislijn
Lijnstuk met een bekende lengte, die je uitzet om een driehoeksmeting te kunnen doen; je doet de hoekmetingen vanaf de uiteinden van je basislijn.

braking distance remweg
Afstand die een voertuig tijdens het remmen aflegt.

C

constellation sterrenbeeld
Groepje sterren dat een herkenbare figuur vormt, met een eigen naam; bekende voorbeelden zijn Orion en de Grote Beer.

counter-pressure tegendruk
Druk van de gassen in een hol voorwerp, die tegen de atmosferische druk in werkt.

D

deceleration vertraagde beweging
Beweging waarvan de snelheid afneemt.

decibel meter decibelmeter
Apparaat waarmee je de geluidssterkte kunt meten.

direct light direct licht
Het licht gaat rechtstreeks van de lichtbron naar het voorwerp.

distance covered afgelegde afstand
Verschil in afstand tussen twee meetwaarden. Het symbool voor afstand is s.

distance-time diagram plaats-tijddiagram
Assenstelsel waarin de plaats (x) is uitgezet tegen de tijd (t).

distance-time table plaats-tijdtabel
Tabel waarin de plaats (x) van een voorwerp op een aantal tijdstippen (t) is vastgelegd.

E

Earth's axis aardas
Denkbeeldige lijn door de beide polen van de aarde waar de aarde omheen draait.

edge ray randstraal
Lichtstraal die net niet door een voorwerp tegengehouden wordt.

ellipse ellips
Soort afgeplatte cirkel.

F

fluorescence fluoresceren
Licht geven als er ultraviolette straling op valt.

frequency frequentie
Aantal trillingen per seconde.

frequency range frequentiebereik
Frequenties die een mens of een dier kan horen.

full moon volle maan
Zo ziet de maan eruit als je tegen het door de zon verlichte deel aankijkt: een grote ronde schijf.

G

galaxy melkwegstelsel, sterrenstelsel
Verzameling van enkele honderden miljarden bij elkaar horende sterren, vaak met opvallende, spiraalvormige armen.

gas giant reuzenplaneet
Planeet die veel groter is dan de aarde en voor een groot deel uit gassen bestaat; een reuzenplaneet heeft geen stevig oppervlak waarop je zou kunnen landen.

H

heat lamp warmtelamp
Lamp die vooral infrarode straling uitzendt.

I

indirect light indirect licht
Het licht gaat niet rechtstreeks, maar via een weerkaatsing naar het voorwerp.

indirect light source indirecte lichtbron
Oppervlak dat licht van een lichtbron weerkaatst.

infrared radiation infrarode straling
Onzichtbare straling die je kunt voelen als warmte.

L

law of reflection spiegelwet
Regel die zegt dat de hoek van inval gelijk is aan de hoek van terugkaatsing.

limit of hearing gehoordrempel
Geluidssterkte waarbij je het geluid net begint te horen.

M

medium tussenstof
Stof waarin de trillingen zich verplaatsen van de geluidsbron naar je oren.

microphone microfoon
Instrument dat drukverschillen in de lucht vertaalt in een elektrisch signaal.

Milky Way Melkweg
Sterrenstelsel waar de zon en de aarde deel van uitmaken. Ook de band van licht die langs de nachtelijke hemel te zien is.

mirror spiegel
Glasplaat waartegen een dun laagje aluminium of zilver is aangebracht.

mirror image spiegelbeeld
Schijnbeeld dat je ziet in een spiegel.

mirror reflection spiegelende terugkaatsing
Het licht wordt gericht teruggekaatst en niet alle kanten op, zoals bij diffuse terugkaatsing.

N

natural light source natuurlijke lichtbron
Een niet door de mens gemaakt voorwerp of verschijnsel dat zelf licht geeft.

new moon nieuwe maan
Zo ziet de maan eruit als de donkere kant naar de aarde toegekeerd is; de maan is dan onzichtbaar.

noise barrier geluidswal/geluidsscherm
Dikke laag aarde langs bijvoorbeeld de snelweg die het geluid absorbeert.

normal normaal
Hulplijn die loodrecht op de spiegel staat.

north celestial pole noordelijke hemelpool
Punt aan de hemel waar het noordelijke uiteinde van de aardas naartoe wijst; alle sterren in het noorden lijken rond dit punt te draaien.

O

oscilloscope oscilloscoop
Instrument dat geluidstrillingen op een scherm weergeeft.

P

pain threshold pijngrens
Geluidssterkte waarbij je oren pijn beginnen te doen.

penumbra halfschaduw
Gebied in de schaduw waar slechts een (klein) deel van het licht kan komen.

phase fase, schijngestalte
Schijnbaar uiterlijk van een planeet of een maan, doordat je alleen het deel kunt zien dat door de zon verlicht wordt (en het niet-verlichte deel onzichtbaar blijft).

plane of the ecliptic ecliptisch vlak
Vlak waarin de baan van de aarde (en dus ook de zon) ligt.

planet planeet
Bolvormig hemellichaam dat in een ellips rond de zon (of een andere ster) beweegt.

pocket spectroscope zakspectroscoop
Instrument om licht te bestuderen. Je kunt ermee zien uit welke kleuren licht bestaat.

prism prisma
Doorzichtig driehoekig stuk glas of kunststof.

R

ray lichtstraal
Rechte lijn waarlangs licht beweegt.

reaction distance reactie-afstand
Afstand die een voertuig aflegt tijdens de reactietijd.

reaction time reactietijd
Tijd tussen het zien van een gevaar en het aangrijpen van de remmen.

reflected diffusely diffuse terugkaatsing
Het licht wordt in alle richtingen teruggekaatst door een object.

S

scale schaal
Verhouding tussen de werkelijke grootte van een voorwerp en de grootte waarop dit voorwerp op een afbeelding is weergegeven.

shadow schaduw
Gebied waar het licht niet rechtstreeks kan komen.

sound insulation geluidsisolatie
Laag isolatiemateriaal om het geluid te absorberen, bijvoorbeeld glaswol.

sound intensity geluidssterkte
De geluidssterkte geeft aan hoe hard een geluid is. De eenheid van geluidssterkte is decibel (dB).

sound source geluidsbron
Voorwerp dat geluid maakt doordat het voorwerp of iets in het voorwerp trilt.

spectral colours spectraalkleuren
De zuivere kleuren in het spectrum.

spectrum spectrum
Reeks opeenvolgende kleuren die bijvoorbeeld zichtbaar is als licht door een prisma valt.

speed of sound geluidssnelheid
Snelheid waarmee het geluid in een tussenstof wordt doorgegeven.

speed-time diagram snelheid-tijddiagram
Assenstelsel waarin de snelheid (v) is uitgezet tegen de tijd (t).

standard pressure standaarddruk
Gemiddelde luchtdruk op aarde op zeeniveau: 1013 hPa.

star chart sterrenkaart
Kaart waarop de sterrenhemel wordt weergegeven zoals die op een wolkeloze nacht te zien is.

stopping distance stopafstand
Totale afstand die een auto nodig heeft om tot stilstand te komen.

stroboscopic photo stroboscopische foto
Foto die is gemaakt in een verduisterde ruimte, met als enige verlichting een stroboscooplamp.

T

terrestrial planet aardse planeet
Planeet die op de aarde lijkt, met een hard, rotsachtig oppervlak waarop planeetverkenners kunnen landen.

time base tijdbasis
Tijdschaal op de oscilloscoop.

triangulation driehoeksmeting
Manier om afstand te bepalen door twee hoekmetingen te doen vanaf de uiteinden van een basislijn.

tuning stemmen
Een muziekinstrument zo instellen dat het een toon met de juiste toonhoogte maakt.

U

ultraviolet radiation ultraviolette straling
Onzichtbare, schadelijke straling die in zonlicht voorkomt.

umbra kernschaduw
Gebied in de schaduw waar helemaal geen licht komt.

uniform motion eenparige beweging
Beweging waarvan de snelheid constant is.

UV lamp uv-lamp
Lamp die vooral ultraviolette straling uitzendt.

V

(v,t) diagram (v,t)-diagram
Andere notatie voor een snelheid-tijddiagram.

vacuum vacuüm
Ruimte waarin geen moleculen zijn en die dus letterlijk helemaal leeg is.

vibration period trillingstijd
Tijd die voor één volledige trilling nodig is.

video recording video-opname
Serie beelden die met korte tussenpozen is gemaakt.

X

(x,t) diagram (x,t)-diagram
Andere notatie voor een plaats-tijddiagram.

Z

zodiac dierenriem
Strook langs de hemel met de twaalf sterrenbeelden, waar de zon in de loop van het jaar voorlangs beweegt.

Index

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